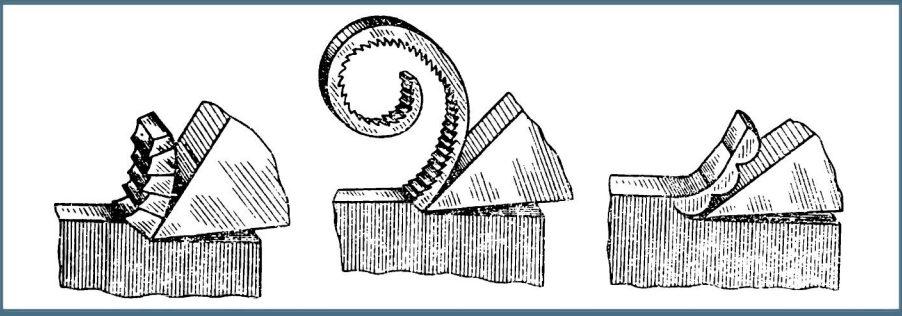
B. Ghenis, L. Doktor, V. Tergan

CYLINDRICAL GRINDING PRACTICE



Mir Publishers Moscow



B. GHENIS, L. DOKTOR, V. TERGAN

CYLINDRICAL GRINDING PRACTICE

Б. ГЕНИС, Л. ДОКТОР, В. ТЕРГАН

ШЛИФОВЩИК НА КРУГЛОШЛИФОВАЛЬНЫХ СТАНКАХ

ИЗДАТЕЛЬСТВО «ВЫСШАЯ ШКОЛА»

На английском языке

B. Ghenis, L. Doktor, V. Tergan

CYLINDRICAL GRINDING PRACTICE

Translated from the Russian
by G. Isserlis

MIR PUBLISHERS • MOSCOW

UDC 621.923:621.924.5(075.3)=20

CONTENTS

Introduction 9

Chapter 1. Engineering Materials 11

1-1. General Information on Metals 11
1-2. Basic Properties of Metals . 12
1-3. Cast Irons . . 19
1-4. Steels 20
1-5. Heat Treatment and Casehardening of Metals 24
1-6. Cutting Alloys 27
1-7. Nonferrous Metals and Alloys . 29
1-8. Corrosion of Metals . . 33
1-9. Nonmetallic Materials . . 35
1-10. The Fabrication of Metals 37

Chapter 2. Reading Drawings 44

2-1. Drawings and Sketches 44
2-2. Methods of Representation in Drawings . . 45
2-3. Lines on Drawings 48
2-4. Dimensioning, Specifying Geometrical Features and Surface Finish on Drawings . . . 50
2-5. Revolved and Removed Sections . . 52
2-6. Other Sectional Views 53
2-7. Representation of Screw Threads and Gears 56
2-8. Assembly Drawings 60
2-9. Graphical Symbols of Machine Parts and Units Used in Diagrams 61
2-10. Rules for Reading Drawings 64
2-11. Taking Measurements 64

Chapter 3. Tolerances and Fits 65

3-1. Interchangeability of Parts 65
3-2. Machining Accuracy 66
3-3. Nominal, Actual and Limiting Sizes . . . 66

3-4. Tolerances 68
3-5. Clearances and Interferences 69
3-6. Fits 70
3-7. Notation of Tolerances and Fits 74
3-8. Grades of Accuracy . . 75
3-9. Surface Finish 78
Chapter 4. Measuring Inspection Equipment and Techniques 82
4-1. Importance of Quality Inspection in Machine Building 82
4-2. Accuracy of Measurement 82
4-3. Instruments for Measuring Linear Dimensions 83
4-4. Instruments for Checking and Measuring Angles 93
4-5. Inspection of Threads 96
4-6. Lever-type Measuring Instruments 97
4-7. Limit Gauges 104
4-8. Gauge Blocks 105
4-9. Optical, Pneumatic and Electrical Measuring Devices 106
4-10. Automatic Gauging in Grinding . . . 108
Chaper 5. Aspects of Engineering Mechanics 111
5-1. Types of Motion . . . 111
5-2. A Force 113
5-3. Friction and Its Role in Engineering 116
5-4. Principles of Mechanisms and Machines . . 117
5-5. Deformation 118
Chapter 6. Grinding Wheels 120
6-1. Types of Cutting Tools and Their Action . . 120
6-2. Abrasive Materials 125
6-3. Grain Size of Abrasive Materials 128
6-4. Bonding Materials 133
6-5. Hardness of Grinding Wheels 135
6-6. Structure of a Grinding Wheel 136
6-7. Wheel Shapes and Marking 138
6-8. Testing Grinding Wheels 140
6-9. Coated Abrasives 141
Chapter 7. The Cutting Process in Grinding 142
7-1. Characteristics of the Grinding Process . . 142
7-2. Grinding Conditions 143
7-3. The Process of Cutting Metal with a Grinding Wheel 146
7-4. Forces Acting in the Grinding Process . . . 150

7-5. Calculation of the Power Required in Grinding 152
7-6. Wheel Life 153
7-7. Heating of the Work During Grinding . . 155
7-8. Cooling and Cooling Fluids 157
Chapter 8. Typical Units of Metal-cutting Machine Tools . . 160
8-1. Classification of Metal-cutting Machine Tools 160
8-2. Gear Trains of Machine Tools 161
8-3. Spindles and Their Supports 162
8-4. Types of Transmission 166
8-5. Hydraulic Drives 177
8-6. Electrical Drives 188
Chapter 9. Electrical Equipment of Metal-cutting Machine Tools 190
9-1. Direct Current 190
9-2. Alternating Current 192
9-3. Induction Motors 194
9-4. Starting Devices 196
9-5. Protective Devices 199
9-6. Electrical Safety Measures 199
Chapter 10. Cylindrical Grinding Machines 201
10-1. Types and Purposes of Cylindrical Grinding Machines 201
10-2. Construction of Cylindrical Grinders . . . 202
10-3. Cylindrical Grinder, Model 312M 204
10-4. Hydraulic System of the Model 312M Grinder 220
10-5. Setting up the Model 312M Grinder for Internal Grinding 224
10-6. Lubrication and Cooling Systems of the Model 312M Grinder 225
10-7. Semiautomatic Cylindrical Grinder, Model 3152 226
10-8. Internal Grinders 229
10-9. Internal Grinder, Model 3250 230
10-10. Centreless Grinding 232
10-11. Centreless Grinder, Model 3180 233
10-12. Service Manual of a Machine Tool . . . 236
10-13. Operating Accuracy of a Grinding Machine 238
10-14. Grinder Maintenance Rules 240
Chapter 11. Grinding Practice 241
11-1. The Manufacturing Process 241
11-2. Selecting the Grinding Wheel 245
11-3. Mounting and Balancing the Grinding Wheel 248

11-4. Truing and Dressing the Wheel 249
11-5. Accessories and Attachments 253
11-6. Preparing and Setting up the Machine for Grinding 264
11-7. Grinding External Cylindrical Surfaces . . 265
11-8. Face Grinding 270
11-9. Grinding External Tapered Surfaces . . . 274
11-10. Grinding Cylindrical and Tapered Holes 280
11-11. Form Grinding 284
11-12. High-velocity Grinding 286
11-13. Automation of Grinding Operations . . . 289
11-14. Rejections and Measures Taken to Prevent Them 291
11-15. Safety Techniques . . . 293
Index 296

INTRODUCTION

Grinding machines are of considerable industrial importance. Grinding, one of the most productive machining techniques, ensures a high surface finish, and high accuracy of the geometrical features and dimensions of the components. Hardened steels and cemented carbides are machined by grinding.

Improvements in blank manufacture are continually reducing the machining allowances and, in consequence, grinding is replacing such operations as turning, planing, milling and bench work to an ever-increasing extent.

The number of grinding machines used in industry is steadily increasing and may, for example, in automobile factories, constitute 25% of the entire equipment. They are particularly widely used in the manufacture of bearings. Their introduction is, however, relatively recent. The first machine for grinding components on the external surface at a speed of 5 to 10 m/sec was built in 1872. The development, at the beginning of the 20th century, of grinding wheels made from artificial abrasive material enabled the cutting speeds to be increased considerably and led to a new stage in the development of grinding machine design. The hand drive system was replaced by belt transmission, and this, in turn, by machines with a geared drive.

Nowadays, machines are built with hydraulic drives; their speeds and feeds can be varied within a wide range. Up-to-date grinders are provided with motorized grinding spindles running at speeds of 100,000 and more rpm.

To increase the productivity, to improve the quality of grinding and to facilitate the task of the workers, grinding

machines are being mechanized and automated. Entire automated production lines have been developed, in which up to 70% of the total number of machining operations involve grinding.

The pattern of mechanization and automation of production processes current in the U.S.S.R. involves a transition from the automation of individual operations and individual machines to the widespread use of electronic computors and control devices thus achieving the automation of large sections of a plant, or of complete shops or factories. Such technological progress will in due course make considerable demands on the general level of skill and education of the workers.

CHAPTER

1

Engineering materials

1-1. GENERAL INFORMATION ON METALS

Commercially Pure Metals and Alloys. The term *metal* is used by chemists to denote only pure metallic elements as classified in Mendeleyev's Periodic System, but in engineering, metals may be of theoretical or commercial purity, or may be alloys. Thus, the term comprises the whole group of metallic materials.

All substances in nature can be classified as simple or complex. Simple substances—elements—are those which cannot be further subdivided by ordinary means. According to the latest developments from Mendeleyev's Table, more than 100 elements exist, of which 78 are metals (mercury, iron, aluminium, lead, copper, tin, etc.).

Complex substances are formed by chemical combination of simple substances. Among complex substances, we must include metallic alloys—cast iron, steel, bronze, brass, silumin, babbitt, etc., which are made by melting together the individual metals, or metals with nonmetals—carbon, sulphur, phosphorus, etc.

In contemporary engineering, pure metals are used much less frequently than alloys, since they are relatively weak and are, moreover, not readily available in many cases (copper, lead, tin, tungsten). Their use is generally confined to applications in which the material is required to possess a high thermal and electrical conductivity, and a high melting point.

Alloys have numerous advantages over pure metals. They are characterized by greater strength, a lower melting point, the ability to change their properties according to chemical composition and as controlled by heat treatment,

and they display a higher fluidity in the molten state and a lower shrinkage.

Groups of Metals. It is usual to consider metals in two large groups: ferrous and nonferrous.

The ferrous metal group comprises commercial iron, as well as steels and cast irons, which are alloys of iron and carbon. In addition to carbon, ferrous metals contain manganese, silicon, sulphur and phosphorus, and may in addition include various alloying elements. This group represents more than 80% of all metals used at the present time. The carbon contents determine the physical and mechanical properties of these metals.

The second group comprises the nonferrous metals—copper, zinc, tin, lead, aluminium, etc., and their alloys.

1-2. BASIC PROPERTIES OF METALS

The properties of the metallic components of mechanisms and machines, their reliability and service life under various service conditions ultimately depend on the specific and inherent characteristics of the metals of which they are made.

The following basic properties of materials are distinguished: physical, mechanical, fabricating and chemical.

Physical Properties. The basic physical properties of metals are: the specific gravity, electrical conductivity, thermal conductivity, melting point, magnetic properties, etc.

The *density* of a material is the weight of one cubic centimetre of the given material in grams. The density of pure iron is 7.87; that of steel, from 7.5 to 10 g per cu cm, depending on its composition. The density of a material is particularly important nowadays, since strength must be combined with economy of weight in a very wide range of engineering applications (e.g., in rocket and aircraft technology, shipbuilding, etc.).

Electrical conductivity, that is, the ability of metals to conduct electric current, is used as a basis for the comparison of pure metals, whereas alloys are characterized by a factor which is inversely proportional to electrical conductivity, namely, the electrical resistivity. The resistance of

a wire of 1 mm^2 cross section and 1 m length is called the specific electrical resistance, which is expressed in ohms. For pure iron the specific electrical resistance at 20°C is equal to approximately 0.1 ohm-mm^2/m.

Thermal conductivity is the ability of metals to conduct heat. The thermal conductivity is the quantity of heat transferred through a unit length of metallic rod of 1 cm^2 cross section in the course of 1 second, with a temperature difference of 1°, and is expressed in cal/cm-sec-degree. Thermal conductivity is of importance in the formulation of specifications for the heat treatment of components, since it determines the rate and uniformity of heating, the rate of cooling, etc.

The *melting point* is the temperature at which a metal passes from the solid to the liquid state. The melting points of pure metals are constant, but alloys melt over a range of temperatures governed by the chemical composition. Among low-melting metals are zinc, tin, lead, bismuth, while high-melting ones are tungsten, molybdenum, titanium, etc.

Magnetic properties characterize the ability of metals to be attracted by a magnet and to be magnetized. In nature there are only four pure metals which possess magnetic properties: iron, nickel, cobalt and the rare metal gadolinium. All the other metals are nonmagnetic. The ability of steel to become magnetized under the influence of a strong magnet is characterized by its magnetic saturation, which is measured in gauss.

An important magnetic characteristic of steel is its ability to remain magnetic. To demagnetize a steel, it must be placed in a magnetic field with its magnetic lines of force in the opposite direction to those of the magnetizing field. The intensity of the demagnetizing field is called the coercive force, and is measured in oersteds.

Mechanical Properties. The mechanical properties of metals include: strength, hardness, elasticity, plasticity and abrasive resistance. These properties exert a decisive influence in determining the suitability of one or another material for specific constructional applications.

Strength is the ability of a metal to withstand various loads without failure.

Hardness is the ability of a metal to resist the abrasive or penetrative effects of contact with other materials.

Elasticity is the ability of a metal to assume its original shape and dimensions after the removal of an applied load.

Plasticity is the ability of metals to deform without rupture during fabrication processes, such as die forging, bending, rolling and drawing.

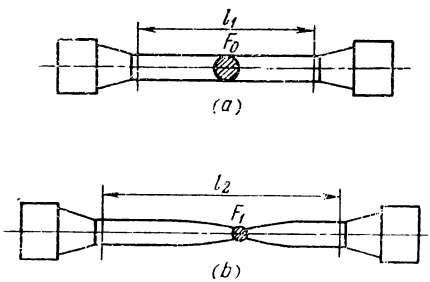


Fig. 1. Tensile-test specimens of metals:
a—before the test; *b*—after the test

The *abrasive resistance* of metals is their ability to resist wear under conditions of friction in service.

The strength and plasticity of a metal are assessed on the basis of tests carried out on standard specimens made from the metal under consideration.

Depending on the type of load which is to act on components made of a given metal, tensile or bending tests of the specimens are carried out.

Tensile tests are carried out in the following manner.

The test specimen (Fig. 1*a*) is placed in the grips of a universal tensile testing machine and a tensile load is applied. As the load increases gradually, the specimen elongates, becomes thinner and then ruptures (Fig. 1*b*). The stronger the metal, the greater the load which must be applied to rupture the specimen. The ductility of the metal may be determined during the same test, since the greater its ductility, the greater the extent to which it will elongate and reduce its diameter. Specimens of brittle materials will rupture at once.

If the load (*P* in kg) at the moment of failure is read off the scale of the tensile testing machine and the cross-sectional area of the specimen prior to testing (F_0 in mm^2) is computed, the ultimate tensile strength (σ_b in kgf/mm^2, i.e., the maximum stress corresponding to the maximum load prior to failure of the specimen) can be determined from the formula

$$\sigma_b = \frac{P}{F_0}$$

where

$$F_0 = \frac{\pi D^2}{4}$$

where D is the diameter of the specimen prior to testing.

The relative elongation may be calculated from the lengths of the specimen before (l_1 in mm) and after (l_2 in mm) testing, by using the formula

$$\delta_n = \frac{l_2 - l_1}{l_1} \times 100\%$$

similarly, the relative reduction in area is given by

$$\varphi = \frac{F_0 - F_1}{F_0} \times 100\%$$

where F_0 = cross-sectional area of the specimen prior to testing, mm^2

F_1 = cross-sectional area of the specimen after testing, measured at the point of rupture, mm^2.

In the course of a tensile test, the following additional strength characteristics may also be determined:

(1) the limit of proportionality (σ_p): the maximum stress to which linear proportionality between the tensile stress and elongation is maintained, i.e., the elongation increases uniformly with the stress;

(2) the elastic limit (σ_e): the maximum stress which can be sustained by the metal without exhibiting permanent deformation after removal of the applied load;

(3) yield point (σ_s): the least stress at which the specimen continues to elongate without noticeable increase in the applied load.

Bend testing is carried out in a similar way.

Hardness testing of the metal is carried out in a device known as the Brinell hardness tester (Fig. 2).

The method of testing consists in forcing a hardened steel ball 10 mm in diameter under the action of a load of, for instance, 3,000 kgf, into a cleaned portion of the surface to be tested. A spherical indentation will be produced in the

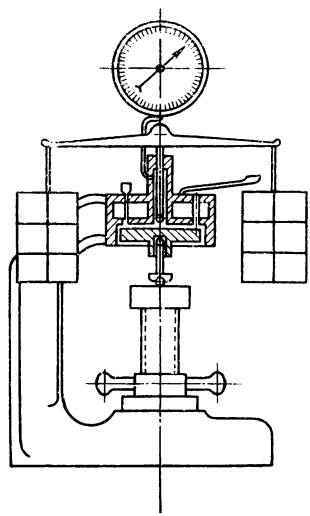


Fig. 2. Brinell hardness tester

flat surface. The diameter of the indentation is measured and its area determined. The Brinell hardness number is determined by dividing the applied load by the area. The higher the hardness number (or the smaller the imprint), the harder is the metal. The Brinell hardness is expressed in kgf/mm^2. If the diameter of the imprint is known, the hardness of a given metal can be determined from special tables.

There is a simple relationship between the Brinell hardness of a steel (Bhn) and its tensile strength, which can be expressed by the formula

$$\sigma_b = 0.36 \text{ Bhn}$$

Thus, if the hardness of the metal is known, its approximate tensile strength can be estimated without testing.

By means of the Brinell hardness tester, the hardness of unhardened steels, cast irons and nonferrous metals can be determined. As the hardness of the tested metal increases, the application of the hardness tester becomes difficult, since deformation of the ball takes place, as a result of which the imprint cannot be accurately measured.

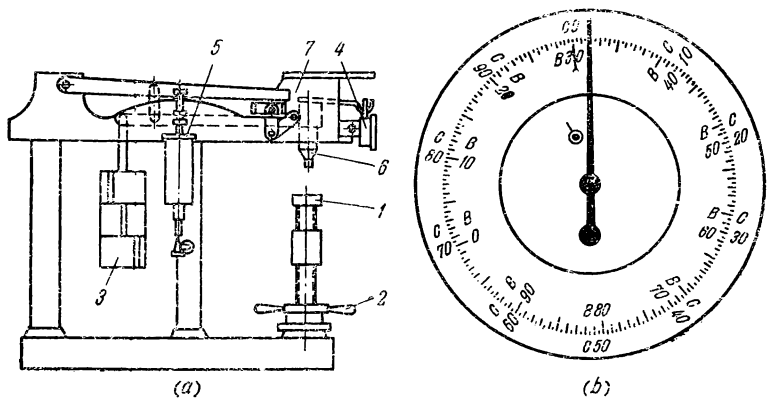


Fig. 3. Rockwell hardness tester:

a—general view; *b*—dial; *1*—table; *2*—handwheel; *3*—weights; *4*—loading indicator; *5*—knife-edge and bearing; *6*—diamond cone penetrator; *7*—rocker arm

The hardness of components less than 3 mm thick cannot be determined by this method. In such cases, the Rockwell tester (Fig. 3) is used. In this test, the indenter (a diamond cone having an apex angle of 120°) is forced into the steel being tested by the application of a load of 150 kgf. For softer materials, a steel ball 1.6 mm in diameter and a load of 100 kgf are applied. The lower the hardness of the steel, the greater the depth to which the diamond cone is forced.

The determination of the hardness of the metal tested is carried out according to the readings of an indicator which has two scales: a black one for a cone and a red one for a ball indentor. In the former case the hardness is designated as R_C, and in the latter as R_B.

Fabricating Properties. The fabricating properties of metals determine their suitability for various manufacturing processes.

Some metals, e.g., steel, copper, aluminium and lead, are readily forged and rolled. Other metals, e.g., cast iron, chromium and aluminium alloys, cannot be forged owing to their brittleness. Cast iron and silumin yield good castings; steel and pure copper are difficult to found. Some metals (e.g., copper and brass) can be readily soldered, while aluminium and its alloys are virtually impossible to solder. The ability of metals to be machined varies: nonferrous metals are easy to machine, whereas cast iron and steel are more difficult. Some metals can be welded satisfactorily. Low-carbon steel is one of them; cast iron, copper and aluminium alloys are less weldable.

The following basic fabricating properties of metals should be mentioned:

machinability, i.e., the ability to be shaped by cutting tools (single-point tools, drills, grinding wheels, etc.);

plasticity, or forgeability, i.e., the ability of metals to be deformed under pressure without failure;

fluidity, i.e., the ability of a metal to fill all cavities of a mould during casting;

weldability, i.e., the ability of separate elements to be firmly joined in the zone of intimate contact under the action of local heating up to the plastic or molten state.

The Structure of Metals and Alloys. All metals and metallic alloys are crystalline bodies; they have a regular internal structure, their atoms are disposed in a strictly defined order and form so-called crystal lattices. At the lattice points in these crystals, there are positively charged ions, which are surrounded by negatively charged electrons; the latter can move freely within the crystal lattice. The mutual attraction between ions and electrons ensures cohesion between the atoms. The smaller the distance between the atoms and the lower the temperature, the stronger will be the bond; a rise in temperature will lead to a weakening of the bond and eventually to disruption of the lattice.

The position of the atoms in the crystal lattice exerts a considerable influence on the properties of metals, as does the size of the crystals themselves. The structure of a cast

metal consists of coarse grains, and the strength of such a metal is not great. The structure of a forged metal is more fine-grained and its strength is considerably higher. The structure of an annealed metal is even finer, and its strength higher still. After hardening, the structure obtained will be the most fine-grained of all, and the strength will be the highest. In alloys, the crystalline body consists of atoms of two or more elements. The properties of alloys depend on the type of elements which they contain, their overall composition, and their internal structure.

1-3. CAST IRONS

Cast iron is a primary product obtained from iron ores, and represents an alloy of iron and carbon, the content of the latter being between 1.7 and 4.5%.

Cast iron is a refined version of pig iron which is the product of the blast furnace process. The raw materials used are iron and manganese ore, coke as the fuel and fluxes, which serve to turn harmful impurities and rock waste into slag. Limestone is used as a flux in blast furnaces.

Coke, ore and flux are charged from above into the blast furnace, in layers. In the upper portion of the stack, at a temperature of 200-400°C, they are heated and dried by an updraught of hot furnace gases. In the central portion of the stack, where the temperature attains 400-800°C, the reduction of iron ore by carbon monoxide, formed by combustion of the fuel, begins. As it descends, the reduced iron dissolves the carbon and other impurities (phosphorus, sulphur, manganese, silicon) at a temperature of 900-1000°C, and still lower in the furnace the iron becomes saturated with carbon and is converted to pig iron. The latter separates from the slag at the bottom of the furnace, and is teemed into a ladle through a special tap-hole.

According to its chemical composition and structure, cast iron is classified as white and grey.

White iron has a high hardness and brittleness, and is consequently difficult to machine by cutting tools. It is less fusible than grey iron. Its main application is as the basis for producing steel, therefore it is also called conversion cast iron.

Grey iron, which is reasonably strong, is easily machinable in metal-cutting machine tools. It has good fluidity in the molten state, fills moulds well and hence is also called foundry iron. This iron can be successfully used for casting various machine frames, components and billets.

Though grey iron has a lower strength than steel, it can withstand reasonably high compressive or bending stresses. In addition, it possesses a high damping capacity for vibrations.

Some articles cast of grey iron must have a hard surface, as in the case of mill rolls, railway wheels, crushing rolls, etc. In such cases, casting is carried out in metallic moulds. On contact with the metallic surface, the cast metal cools quickly and acquires a hard crust of white iron. Cast iron having a surface structure of white and a core of grey iron is called chilled cast iron.

Apart from the basic types of normal grey cast iron, there are so-called inoculated cast irons, high-strength spheroidal graphite irons, alloyed cast irons, as well as malleable irons, which are produced by annealing white iron at a temperature of approximately 900°C. Malleable iron is relatively ductile, readily worked by cutting tools and in many cases replaces steel castings of complex shape.

Specifications for grey cast irons are formed by adding two pairs of digits to the letters СЧ*. The first pair denotes the minimum tensile strength and the second pair, the minimum strength in bending, e.g., СЧ12-28, СЧ18-36.

1-4. STEELS

Steels, like cast irons, are alloys of iron and carbon. Cast irons, however, have a higher carbon content, and steels are made from them by removing the surplus carbon.

Production of Steel. According to the mode of manufacture, steels may be classified as Bessemer, Thomas, open-hearth, crucible and electric steels.

Bessemer and Thomas steels are made by blowing air through the molten iron in converters. The excess carbon is thereby burnt out. At the same time, however, during the

* The Russian letters СЧ represent the first letters of the Russian words «серый чугун» meaning grey cast iron.

process of blowing, the steel is agitated and is contaminated by slag inclusions and dissolved gases. Such steels have a higher content of phosphorus and nitrogen, which increase the brittleness of the metal.

The shortcomings of converter melting also include the impossibility of reprocessing metallic scrap, the necessity to work with molten iron of a definite composition, an appreciable wastage of metal, etc. On the other hand, this method has a whole range of advantages, namely, a high output, simple and cheap plant, no need for fuel, and a relatively cheap product.

In the *open-hearth method*, the refining process can be regulated and a steel of controlled composition produced.

The *crucible and electric methods* are used for the production of high-quality special steels by remelting ordinary steel in crucibles and electric furnaces.

According to the composition of the furnace constituents and charge, steels may be classified as acid or basic. Acid steel contains less oxides and therefore possesses better mechanical properties. During the production of basic steel, phosphorus and sulphur can be effectively removed and this method is therefore essential for the conversion of phosphorous pig irons into steel.

The acid Bessemer method gives acid steel, the Thomas method, basic steel. The open-hearth method can yield either acid or basic products.

Types of Steel. According to their chemical composition, steels are classified as carbon steels, the mechanical properties of which are determined by the carbon content, or as special (alloyed) steels, the mechanical properties of which are influenced by such alloy elements as tungsten, chromium, nickel, molybdenum, vanadium, silicon, manganese, etc.

According to the field of application, distinction is made between structural steels, tool steels and steels with special physical and chemical properties (acid-resistant, heat-resistant, stainless, etc., steels).

The quality of a steel is determined by its purity, i.e., by the relative absence of harmful impurities and slag, as well as of defects (blow-holes, cracks, etc.).

Structural carbon steels contain between 0.05 and 0.63% carbon. Soft steels with a low carbon content (0.1-0.3%) can

be welded without difficulty, can be cut by a gas flame, and are easily bent and cold-forged. They are, however, virtually unaffected by heat treatment (hardening).

Steels of higher carbon content (0.4-0.6%) possess a high strength, elasticity and hardness, and respond to hardening. Various machine parts are made from these steels, and hence the name *machine steels*.

Structural steels are divided into ordinary steels (Group A), improved steels (Group B) and quality steels.

Ordinary structural steels are divided into 8 grades, namely, Ст.0, Ст.1, Ст.2, Ст.3, Ст.4, Ст.5, Ст.6 and Ст.7. The higher the number of the steel, the more carbon it contains.

Ст.0 is the lowest in quality and is used for the manufacture of unimportant parts.

Ст.1, Ст.2 and Ст.3 are highly plastic and ductile. They are readily welded, forged and stamped. Riveted and welded structures are made from these steels, e.g., bridges, girders, tanks, boilers, as well as bolts, nuts, rivets, nails, etc. Gears, shafts and other parts which are subsequently case-hardened are also made of these steels.

Steels Ст.5 and Ст.6 have a higher strength, and they are made into high-strength components, as well as into shafts, axles and tires. These steels are more difficult to weld and cold-forge, but respond well to hardening.

Improved structural steels are classified, according to the method of manufacture, as open-hearth (МСт.) and Bessemer (БСт.) steels and are known, respectively, as МСт.0, МСт.1, МСт.2, МСт.3, МСт.4, МСт.5, МСт.6 and МСт.7 and БСт.0, БСт.3, БСт.4, БСт.5 and БСт.6.

Quality structural steels are available in 14 grades, namely, 08, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65 and 70. These grades are not denoted by any letter code. The figures signify the number of hundredths of one per cent of carbon contained in the steel. These quality structural steels are considerably more homogeneous than the ordinary ones but, being more expensive, they are used only for important components.

Alloying elements exert a considerable influence on the properties of steels. Chromium increases their hardness, strength, elasticity, high-temperature strength, heat resistance, hardenability and also the resistance to corrosion,

Nickel increases their ductility, strength, resistance to corrosion, electrical resistance and hardenability, self-hardening properties and improves their magnetic qualities.

Tungsten increases the strength and hardness, imparts stability at high temperatures to the steel, raises the hardenability and self-hardening properties.

Vanadium increases the strength, elasticity, hardness and ductility of a steel.

Molybdenum increases the strength, hardness, elasticity, chemical stability, hardenability and self-hardening properties of the steel.

Alloyed structural steels contain up to 0.6% carbon and up to 5% alloy elements. They are used for important components in the automobile, aeronautical and other branches of industry.

The types of alloyed structural steels are denoted by a letter-number system. A pair of numbers is first used to denote the carbon content in hundredths of one per cent, and letters are appended to indicate the alloying elements as follows: Х—chromium, Г—manganese, Н—nickel, Ф—vanadium, М—molybdenum, В—tungsten, Ю—aluminium, С—silicon, Д—copper, К—cobalt and Т—titanium.

The content of each alloying element, if it exceeds 1%, is indicated after the appropriate letter. If at the end of the specification of the type of alloyed steel there is the letter А, this means that this steel is of high quality.

For instance, steel 12ХН3А is a high-quality, chromium-nickel steel, containing 0.12% carbon, approximately 1% chromium and approximately 3% nickel.

Carbon tool steels, which contain 0.6-1.4% carbon, are also classified as quality and high-quality steels. They are used for the manufacture of various impact, cutting and measuring tools. After hardening, tool steels possess a high hardness and wear resistance. According to the U.S.S.R. standard they are subdivided into 16 grades, of which half comprise the quality, and half the high-quality steels: У7, У7А, У8, У8Г, У8А, У8ГА, У9, У9А, У10, У10А, У11, У11А, У12, У12А, У13, and У13А.

The letter У implies that the steel is a carbon steel, the number following the letter У indicates tenths of 1% carbon content, and the letter А denotes a high-quality steel.

Impact tools are made of steel of lower carbon content, since such a steel is less brittle. For instance, chisels, forging dies, hammers and axes are made from steel У7, while pressworking dies and blades for shearing metals are made of steels У8 and У9. Cutting tools are made of the harder types of steel У10 and У12.

Alloyed tool steels contain up to 1.5% carbon and a considerable proportion of alloying elements, and hence possess a longer service life than the carbon tool steels.

Alloyed tool steels of high alloying element content, with tungsten, chromium and vanadium in particular, are called *high-speed steels.* These steels can retain their hardness even at temperatures of 500-600°C, and may thus be used at higher cutting speeds. They are used in the manufacture of single-point tools, drills, milling cutters, screw taps and other cutting tools.

The commonly used high-speed steels are classified as follows: Р18, Р9, ЭИ347, РК5, РК10, Р9К5 (ЭИ705), Р9Ф5 (ЭИ706). The numbers following the Russian letter Р, which stands for "rapid", indicate the percentage of tungsten, and those following the letter К, the percentage of cobalt.

Steel Р18 is the one most widely used in the manufacture of cutting tools; it possesses a high strength and red-hardness. The steels РК5 and РК10 are also characterized by high red-hardness.

The alloyed tool steels 5ХГМ and 6ХС possess a high ductility and are used for the manufacture of dies, blades for the cold shearing of metal and other impact tools. The steels 9ХС, ХВ5 and В1 are used for the manufacture of drills, milling cutters, single-point tools and other types of cutting tools, since they acquire a great hardness after heat treatment. The steels ХГ and ХВГ show little deformation during service and are used for the production of measuring tools.

1-5. HEAT TREATMENT AND CASEHARDENING OF METALS

Heat Treatment. This involves changing the physical, mechanical and fabricating properties of metals and their alloys by heating and cooling. The main aspects of heat treatment are: annealing, normalizing, hardening and tempering.

Annealing consists in heating a steel to a definite temperature, soaking until the temperature is uniform throughout, followed by slow cooling. The necessity of annealing is associated with the fact that, as a result of certain aspects of working (forging, stamping, drawing, etc.), the metal becomes harder. Previous working also often induces harmful internal stresses in the metal. All these defects are removed by correct annealing. During annealing, the structure of steel remains essentially unchanged, since during slow cooling the particles of iron and carbon can regroup themselves in the same way as they were grouped prior to annealing. At the same time the steel becomes soft and ductile.

Normalizing is a process similar to annealing, but the cooling rate is higher, cooling being usually performed in air. As a result of normalizing, the steel acquires a more fine-grained structure and greater strength and hardness than in annealing.

Hardening consists in heating the steel to a definite temperature (not less than 750°C), soaking and rapid cooling (quenching) in a quenching medium.

The essence of hardening consists in the fact that on heating to high temperatures, the steel changes its structure. Upon quenching, a different grouping of iron and carbon particles occurs in the steel and the grains formed are not only very fine, but actually make up a different structure. As a result, the steel becomes very strong, hard and less ductile. The higher the carbon content of the steel, the more easily is this structure attained.

For components whose wear resistance under conditions of impact loading is of importance (gears, shafts, etc.), an inhomogeneous structure is essential—a soft core and a hard surface layer. In such cases, the metal is surface-hardened so that a change in structure occurs to a shallow depth.

If hardening is to be limited to the surface, the components must not be heated throughout. Only their surface layer is heated, and this is followed by quenching.

Tempering consists in reheating the hardened steel to a temperature not exceeding 700°C, soaking, and subsequent cooling in air, oil or water. Tempering is applied to remove

any internal stresses which arise during quenching, and to reduce the brittleness of the metal.

As the tempering temperature is raised, the hardness of the hardened steel decreases. The tempering temperature is therefore kept as low as possible (180-220°C), to reduce the brittleness and remove internal stresses, while at the same time preserving the maximum hardness and wear resistance of the metal. Intermediate tempering temperatures (300-500°C) are used where high ductility must be combined with adequate strength and elasticity (e.g., in connecting rods and similar components).

Subzero treatment. After normal quenching and tempering, internal structural changes in the steel continue for a long time and cause variations in the dimensions and shape of manufactured articles. For this reason, critical components and cutting or measuring tools may be cold-treated subsequent to quenching and tempering, in order to stop internal changes. The temperatures used are between —12 and —120 C. These low temperatures are attained with the aid of liquefied gases, such as oxygen, air, freon, etc.

Subzero treatment increases the hardness and stabilizes the dimensions and shape of the articles. To remove the internal stresses which arise in the course of freezing, the article is subsequently retempered.

The casehardening of metals includes carburizing, nitriding, carbonitriding, cyaniding, calorizing*, etc.

These operations, in contrast to heat treatment, are characterized by the fact that while the articles are being heated, their surface is saturated with various agents (carbon, nitrogen, aluminium, etc.). This ensures a high surface hardness whilst leaving the core soft and tough.

Carburizing is a process in which the surface of steel articles is saturated with carbon. It is applied to components subject to wear under impact loads (gears, wrist pins, etc.). Mild steel articles of low carbon content (below 0.3%) are used for such applications.

Carburizing is carried out by means of solid, liquid or gaseous materials—carburizers. In pack carburizing, a sur-

* Actually calorizing, or aluminium impregnation, is considered to be a metallic cementation or diffusion coating process.

face layer 0.5 to 2 mm deep containing from 0.9 to 1.2% carbon is produced. The average rate of carburization is 0.1 mm/hr. Liquid carburizing is carried out by immersing the articles in a bath containing molten cyanide salts. The process is sometimes called cyaniding when the percentage of cyanide salts in the bath is high. The depth of cyaniding is 0.15-0.30 mm and the carbon content of the case (surface layer), 0.4-0.8%. Gas carburizing is accomplished in furnaces at a temperature of 920-940°C. This method is much quicker than the other processes, a carburized layer 1.1-1.3 mm deep being obtained in 4-6 hrs. After carburizing, the articles are quenched and tempered.

Nitriding is a process in which the surface of articles made of special steels is saturated with nitrogen to increase their hardness and wear resistance. Prior to nitriding, the articles are subjected to finish machining, and only a small allowance is left for finish grinding or polishing. Nitriding is carried out in a closed furnace, in which the articles are held at a temperature of 500-550°C for 30-60 hrs, after which they are slowly cooled.

In nitriding, the hardness of the surface layer is higher than that obtained by carburizing. Valves, crank shafts, measuring tools, etc., are treated by this process.

Calorizing (aluminizing) is a process in which the surface of the steel is impregnated with aluminium to increase the heat resistance. Calorizing is applied to articles exposed to high temperatures under service conditions (up to 1000°C).

1-6. CUTTING ALLOYS

Cutting alloys are metallic alloys possessing a very great hardness, wear resistance and the ability to retain these properties at high temperatures.

A cutting tool tipped with a suitable cutting alloy enables the cutting speeds to be considerably increased, in a number of cases, to as much as 700-800 m/min. When cutting alloys are used in the manufacture of dies, excavator teeth, hammer drills, blades for cutting metals, etc., longer service lives are obtained, and wastage of metal is reduced.

Depending on the method of production, distinction is made between cast cutting alloys, cemented carbides,

granular hard-facing materials and hard-facing electrodes.

Cast cutting alloys (relite, sormite, stellite, etc.) are produced in electric furnaces. Alloys of this group come under two headings: cast high-melting carbides, which are used, as a rule, only in oil drilling equipment, and alloys of the stellite type, which are available in the form of round cast rods and may be weld-deposited in an oxy-acetylene flame on rapidly wearing machine and tool parts. Hard-faced tools can machine hard materials at temperatures of 500-600°C. The wear resistance of hard-faced components rises 5 to 10 times.

Cemented carbides are made by sintering compacted, fine-grained, high-melting carbides of tungsten and titanium together with powdered cobalt, at a temperatures of 1350-1400°C. The carbides constitute the main bulk of such alloys (85-97%). The auxiliary metal plays the role of a binder, which ensures a satisfactory strength and ductility for the alloy.

Three types of cemented carbides are available in the U.S.S.R.:

alloys of the tungsten group (ВК2, ВК3М, ВК4, ВК4В, ВК6М, ВК6, ВК6В, ВК8, ВК8В, ВК10, ВК15, ВК20, ВК25 and ВК30) are used for the machining of cast iron, steel and nonmetallic materials (plastics, rubber, porcelain, glass, stone, etc.);

alloys of the titanium-tungsten group (Т30К4, Т15К6, Т14К8, Т5К10, Т5К12В) are used only for the machining of steel;

alloys of the titanium-tantalum-tungsten group (ТТ7К12) are used to machine off surface layers of steel forgings and castings containing flaws, particles of sand, slag, or various nonmetallic inclusions, or when the cross section of the stock to be removed is uneven, etc.

Cutting alloys are specified in terms of the following letter code: В—tungsten carbides, К—cobalt, Т—titanium carbides.

Numerals after the letters show the percentage of a given metal contained in the alloy. For instance, the cemented carbide Т5К10 contains 10% cobalt, 5% titanium carbides, the balance being tungsten carbides.

Among *granular hard-facing alloys* are wocar, a mechanical mixture of tungsten and carbon, and stalinite, a mixture of ferrochrome, ferromanganese, cast iron chips and coke. These alloys, which are available in the form of grains 1-3 mm in diameter, are used as a filler metal for hard-facing articles subject to heavy wear (boring bits, teeth of excavator buckets, etc.).

Hard-facing electrodes consist of pieces of electrode wire 400-500 mm in length and 3-6 mm in diameter, coated with a special composition. Hard-facing is performed by means of an electric welding apparatus.

Apart from cemented carbides, ceramic-tool materials are also used in the manufacture of cutting tools. These are made from alumina (Al_2O_3)—corundum, by compacting and subsequent heat treatment.

The ceramics possess a very high red-hardness, a high dimensional stability and ensure a high finish of the machined surface; ceramics are also extremely cheap and do not contain metals in short supply, such as tungsten, titanium or cobalt.

Cutting tools with ceramic tips can operate at very high cutting speeds. Progressive lathe operators, using ceramic-tipped tools, have attained cutting speeds of up to 1,800-2,000 m/min in the finish-machining of steel and cast iron. However, ceramic-tool materials have one serious shortcoming. They are very brittle (they cannot withstand impact loads) and they are unstable. In consequence, their field of application has been somewhat limited so far.

At present, ceramic-tool materials of the types ЦВ (thermocorund) and ЦМ (microlite) are being mass-produced in the U.S.S.R. Ceramics of the types ЦВ-13, ЦВ-18 and ЦМ-332 are beginning to be widely used as substitutes for high-speed steel and cemented carbides in the finish and semifinish turning of steel, cast iron and nonferrous metals.

1-7. NONFERROUS METALS AND ALLOYS

Nonferrous metals are widely used in mechanical engineering both in the pure state (copper, tin, zinc, lead, aluminium, etc.), and in the form of various alloys (bronze, brass, babbitts, solder, silumin, duralumin, electron, etc.).

Copper is a soft and ductile metal, possessing a high electrical conductivity, thermal conductivity and resistance to corrosion. It lends itself readily to fabrication by hot and cold mechanical working processes. Copper is used in all branches of industry in the form of pipes, wire, rods, anodes and, in addition, forms the main constituent of the copper-nickel alloys, bronze and brass.

Tin is a soft and ductile metal of silvery white colour. It possesses highly anticorrosive properties, withstands mechanical working well, and is used for soldering, tinning and in the production of foil. Tin is one of the constituents of many commercial alloys (e.g., bronzes, babbitts, solders, etc.).

Zinc is a brittle metal of greyish white colour. It lends itself to hot rolling, pressing and wire drawing. It is irreplaceable in the printing trade for the production of clichés, and is also used for the galvanizing of steel sheets and in the production of brass and brazing filler metals.

Lead is a soft and ductile metal of greyish blue colour. It is readily worked in the hot and cold state, and possesses a high resistance to the action of acids. It is used for the manufacture of etching baths, storage batteries, cable sheathing, electric fuses, etc., as well as for the manufacture of babbitts, lead bronzes, solders, etc.

Aluminium is a soft and ductile metal of white colour, possessing a high plasticity, good thermal and electrical conductivity and anticorrosive resistance. It is widely used in the electrical and aeronautical industries, in the manufacture of consumer goods, and also in the production of silumins, duralumins, etc.

Magnesium is a light metal of silvery colour, which is not used in the pure state, since it is prone to severe oxidation and in addition possesses low mechanical properties. It is used as the base for magnesium alloys, and forms a constituent of aluminium alloys.

Alloys. Among the series of copper alloys, the most widely used ones are bronzes and brasses.

Bronzes are alloys of copper with tin, lead, aluminium, manganese or silicon. Depending on the principal element alloyed with copper, bronzes are classified into tin, lead, aluminium, manganese, silicon, etc., bronzes. Tin is an

expensive metal in critical supply, and other bronzes are therefore more widely used.

Bronzes withstand wear and corrosion, and also possess antifrictional properties. They are thus used for the manufacture of bearings, bushes, bearing inserts (БрС30), components of steam and water fittings (БрОЦС6-6-3), rims of gears (БрАЖМц10-3-1.5), etc.

In particular, the inserts of sliding friction bearings for the spindles of grinding and precision machines designed to work at high speeds, in the order of 5-10 m/sec, and high loads of more than 100 kgf/cm^2 are made of the high-quality antifriction alloy БрС30. The bearing inserts for the main spindles of machine tools are made of the secondary antifriction alloys БрОЦС6-6-3 and БрОЦС5-5-5.

The composition of the various types of bronzes is denoted as follows: Бр—bronze, О—tin, Ц—zinc, С—lead, Н—nickel, i.e., the letters denote the main constituents of the alloy. The numerals following the letters give the average percentages of the elements in the alloy. For instance, the composition of the bronze БрОЦСН3-7-5-1 is: tin 3%, zinc 7%, lead 5%, nickel 1%, balance—copper.

Brasses are alloys of copper and zinc. These alloys, which occasionally contain additions of tin, aluminium, lead and nickel, are the most widely used nonferrous alloys; they are called special brasses. The above constituents impart increased strength, hardness and corrosion resistance to the alloys and improve their casting properties. Additions of lead facilitate the machining of the alloys.

Brasses are marked by the letter Л followed by numerals indicating the average copper content; if the brass contains another element apart from copper and zinc, then it is denoted by a letter indicating the name of that element and a numeral showing its average content.

Brass of low zinc content (below 22%) is called *tombac*. The latter is very soft and ductile and is therefore very suitable for forging, pressing, stamping and drawing in the cold and hot states. Brasses of high zinc content can be forged and stamped only in the hot state.

Brasses are widely used in the manufacture of radiators, condensers and in shipbuilding and mechanical engineering.

Aluminium alloys have found wide application in various fields. They are characterized by lightness and possess satisfactory strength and ductility. Most aluminium alloys are of the duralumin or silumin types.

Duralumins are alloys of aluminium with copper, magnesium, silicon and iron. To increase the resistance of these alloys to corrosion, manganese is also added. Duralumins possess high strength, hardness and considerable ductility.

Duralumins are denoted by the letter Д followed by a numeral standing for the particular alloy. The normal (grade Д1) duralumin is used in the form of strips, sheets, tubes, sections and components. The high-strength type Д6 alloy, containing a higher proportion of reinforcing elements (copper, magnesium and manganese) is used for the manufacture of heavy-duty bearing components of the airframe and sheathing of aircraft. The high-strength type Д16 alloy undergoes cold bending satisfactorily, and has a wide quenching temperature range and high strength and ductility in the annealed and heat-treated state.

Silumins are aluminium alloys with a high content of silicon (up to 13%), and copper (up to 6.5%), magnesium (up to 0.6%) and manganese (up to 0.5%). They possess excellent casting (low shrinkage) and mechanical properties (considerable strength, ductility and low specific gravity).

The high mechanical properties of these alloys are due to their fine structure, which is achieved by modification and heat treatment (quenching from 525-535°C and prolonged ageing). Modification consists in adding metallic sodium or mixtures of sodium fluoride and sodium chloride to the molten alloy at 750-780°C.

Aluminium casting alloys, including the silumins, are denoted by the letters АЛ and the specific number of the alloy.

The most important heavy-duty parts of motors, such as crankcases, housings, cylinder blocks and heads, are cast of silumins of the types АЛ4, АЛ5 and АЛ9.

Magnesium alloys. The main characteristic of magnesium alloys is their light weight. For the casting of components of complicated shape, magnesium alloys containing aluminium (up to 10%), zinc (up to 2%), manganese and silicon are most widely used. Such alloys are known as *electrons*.

Magnesium alloys are very light and strong, but they have a low resistance to corrosion. To increase their corrosion resistance, manganese is added to them and protective coatings are applied (paint, lacquer coatings, etc.). Zinc is added to magnesium alloys to improve their mechanical properties; this may also be achieved by heat treatment (quenching and ageing).

Magnesium alloys come under two main classifications: wrought (deformable by pressure) and cast (for the production of castings of complicated shape). The wrought alloys are denoted by the letters МА, and the cast alloys, by МЛ; the numerals following the letters show the number of the alloy.

Tin- or lead-base *antifriction alloys* (babbitts) are used for the casting (babbitting) of bearings. The function of these alloys is to reduce the friction and wear of rubbing surfaces. After solidification, a bearing alloy contains two structural constituents: a soft structural matrix (of lead or tin) in which hard particles (antimony, copper, cadmium, nickel, calcium, etc.) are embedded. The soft matrix adjusts itself closely to the shaft, and the hard particles, which support the weight of the shaft as the matrix recedes, withstand high pressures satisfactorily. A network of extremely fine channels forms on the bearing surfaces, and these retain and distribute the lubricant. The tin-base babbitt Б83 (containing 83% tin) is used in bearings of heavy-duty machine units (powerful motors, turbines, compressors, etc.), whereas the low-tin babbitt Б16 and the tin-free alloy БК are used in lighter-duty installations.

Babbitt alloys are widely used for the bearings of grinding machines, the working spindles of which experience high specific pressures and run at high speeds.

Lately, to save tin and lead, which are in short supply, laminate fabric base, bakelized wood, various plastics, antifriction grey irons and other materials are being used as bearing materials.

1-8. CORROSION OF METALS

Corrosion is the destruction of metals by the action of the surrounding medium (air, water, chemical products and their vapours). The majority of metals, with the exception of

the so-called precious metals (gold, platinum, etc.), are liable to corrode to a greater or lesser extent.

Due to the interaction of the metal surface with oxygen, a surface film of metal oxide forms, this being the corrosion product. The rate of oxidation increases with the moisture content of the air, its temperature and pressure, and when the temperature variations are great. The presence of chemical reagents (acids, salts, alkalis, etc.) in the premises accelerates this process.

Distinction is made between *chemical* and *electrochemical* corrosion. The former occurs as a result of the action of dry gases, or of liquids which do not conduct electric current (formation of an oxide film on heating the metal, oxidation of copper in air, etc.).

Electrochemical corrosion arises due to the action of liquids capable of conducting electric current (destruction of metals due to the action of acids, salts, etc.).

Corrosion may be distributed over an entire exposed surface; this is *uniform* corrosion. Alternatively, it may be localized in certain regions. *Intercrystalline* (or *intergranular*) corrosion causes the cohesion between the individual metal grains to deteriorate, and hence lowers the strength of the metal.

The methods used nowadays to combat corrosion include the following:

(1) nonmetallic coatings (paint, lacquers and slushing compounds);

(2) metallic coatings of tin, aluminium, nickel, chromium, zinc, etc;

(3) chemical coatings (oxidizing, phosphating, bluing), produced by the action of acids, salt solutions, etc., on the metal;

(4) addition of chromium, nickel, titanium, tungsten, molybdenum, etc., to alloys, so as to obtain an oxide film on the metal surface.

In grinding operations, the protection of components against corrosion between operations is of considerable importance. For this reason, semifinished work is washed in aqueous solutions of emulsol (soluble oil) and then held in these solutions for three to five days. Triethanolamine and sodium nitrite solutions are most widely used for interop-

erational protection against corrosion. Components washed in such a solution are then dried in air, whereupon a protective film remains on the metal surface.

In those cases where storage in aqueous solutions or under films of such solutions is inadmissible, the parts are stored in enclosed containers with silica gel. The use of silica gel is based on its ability to absorb moisture from the atmosphere, as a result of which the moisture content of the air in the enclosed space decreases to such an extent that corrosion cannot take place.

Lately, volatile inhibitors have found wide application. These are compounds which prevent the oxidation of metals. Typical compounds of this kind are ammonium nitrite, the double nitrites of ammonium and copper, and aminoalcohols and their compounds with acids, etc. The most widely used inhibitors are monoethanolamine carbonate, dicyclohexylamine nitrite and cyclohexylamine carbonate.

1-9. NONMETALLIC MATERIALS

Apart from metals, nonmetallic materials, such as wood, rubber, glass, plastics, various auxiliary materials, etc., are widely used in mechanical engineering.

Wood in the form of timber, plywood, veneer and densified laminated wood is used as a structural material. The advantages of wood are its low specific gravity, relatively high strength, low thermal conductivity, good machinability and ability to absorb impacts due to its elasticity.

Wood is used for the manufacture of patterns in the foundry industry, for the manufacture of antifriction parts (bearing linings, etc.), the bodies of motor-vehicles and various types of processing equipment (tanks, solution agitators, etc.).

The disadvantages of wood are its tendency to rot, its combustibility, and the high and constantly changing moisture content. To increase its resistance to rotting, it is saturated with anticeptics, and may also be coated with lacquers or paint.

Vulcanized rubber, a chemical transformation product of natural rubber, is widely used in industry for the manufac-

ture of sealing rings, membranes, shock absorbers, inner tubes and tires for automobiles, etc.

Rubberized fabric is used for the manufacture of flexible hoses, transmission belts, conveyor belts, etc.

Storage battery tanks, steering wheels and various components of electrical and radio equipment are made of hard rubber (ebonite).

Plastics are made by mixing synthetic and natural resins with various other compounds. Articles made of plastics can be shaped by various methods (e.g., compression moulding, injection moulding, etc.).

Plastics come under two basic categories: thermoplastic and thermosetting plastics.

The majority of polymerization plastics are *thermoplastic materials* (polyethylene, polystyrene, polyamides, polyesters, etc.). Articles can be made from such plastics by up-to-date and economic methods, such as injection moulding, extrusion and calendering.

Thermosetting plastics comprise phenoplasts, aminoplasts and certain other materials. Articles are usually made from these plastics by compression moulding.

Plastics possess good physico-chemical and mechanical properties—low specific gravity, satisfactory strength, high chemical stability, the ability to form thin films and either good frictional or good antifrictional properties.

In industry, such types of plastic materials as laminated plastics based on phenol aldehyde, polyester, epoxy or other resins are widely used. Laminated plastics are made by impregnating cotton or glass fabric with synthetic resins and subsequent pressing. They are used in the manufacture of bearings and gears.

Phenoplasts are made of phenol aldehyde resins together with such powder fillers as wood flour and quartz flour, mica, etc. Phenoplast articles do not soften on heating, and are not subject to the action of hot oils and organic solvents. They are therefore widely used in the automobile, radio and aeronautical industries.

The *auxiliary materials* embrace lubricants, cutting fluids, packing materials, etc.

Lubricants are used to reduce the friction between moving machine parts, and hence to reduce power consumption

and the wear of rubbing parts, as well as for the protection of the components against corrosion.

The following lubricants are used:

(1) mineral oils (made of petroleum, lignite and coal, bituminous shale) are the most widely used and cheapest lubricants;

(2) vegetable oils (linseed oil, cottonseed oil, burdock oil, etc.) are fairly expensive lubricants. They dry out relatively quickly and decompose into their constituents, and are therefore more often mixed with mineral oils;

(3) greases consisting of a mixture of soaps and oils are used for lubricating heavy-duty surfaces working at low rubbing speeds.

Cutting fluids improve the cutting of metals, and increase the efficiency of grinding.

Cutting fluids include oils, oil emulsions and aqueous media, kerosene and other mixtures of various compositions. Oily liquids are more effective as lubricants, since they decrease the quantity of heat evolved during the cutting of metals, while aqueous solutions, though they allow more intense generation of heat, exert an appreciable cooling action.

Packing materials ensure intimate contact between separate components with the aim of preventing any loss of liquids and gases at the joints. They include: rubber, paper, fibre, leather, cardboard, tow, etc.

1-10. THE FABRICATION OF METALS

Various methods of fabrication are available for the manufacture of machine parts and other articles: casting, stamping, forging, machining, etc.

Foundry Practice. Castings are made by pouring molten metal into a mould, the shape of which corresponds to that of the parts to be made. The metals used may be cast iron, steels or various alloys, and the castings produced may be finished articles, or may be used as blanks for subsequent machining.

For the production of a casting, a pattern and sometimes a core box are required. The pattern, in its external shape, corresponds in most cases to the external shape of the parts

to be cast. In the core box, a core sand mix is formed into a core corresponding in shape to that of the cavity in the casting.

The materials used for patterns and core boxes in small-batch production are wood, clay and cement, and in mass production—aluminium alloys.

The mould into which the metal is poured is usually made of a moulding mixture contained in two frames, called flasks. The basic components of moulding mixtures are moulding sand, which has a homogeneous structure, clay and water. The moulding process can be carried out either by hand or by machines.

There are several methods for the production of castings. In *permanent-mould casting*, metal moulds are used. In contrast to expendable sand moulds which are used only once and are destroyed during the removal of the casting, metal moulds are used many times.

In *centrifugal casting*, the molten metal is introduced into a rapidly revolving mould, where it is thrown against the wall under the action of the centrifugal force. It then solidifies, forming an internal shell of cylindrical shape. This method is widely used for the production of tubes, sleeves, etc.

Die casting is carried out in metal moulds. In this method, the metal is forced into the mould under pressure and the finest shapes may therefore be reproduced exactly. Die casting is used in the mass production of small, shaped, thin-walled parts, components of instruments, etc.

Small parts requiring no subsequent machining may be made by *investment casting* techniques.

Casting into shell moulds enables the quantity of mould materials to be reduced, renders the use of flasks unnecessary and produces accurate castings of a surface finish so high that machining is not required in many cases. This method of casting is used in mass and lot production.

The main types of defects in castings are blow-holes, cracks, warpage and porosity. Blow-holes extending to the surface are easily visible directly, or under low magnification. Cold cracks in the form of thin hairlines are characterized by a bright fracture. Hot cracks are shallow and are distinguished by a ragged appearance and an oxidized surface.

The Mechanical Working of Metals. Forming processes involving mechanical deformation are based on the utilization of the plastic properties of metals. Distinction is made between cold and hot working processes. The heating equipment in which metals are preheated before hot working may consist either of normal (fuel-fired) or electric induction

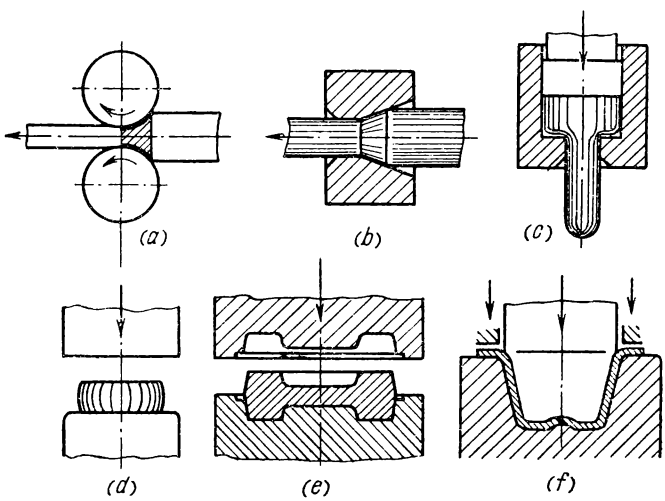


Fig. 4. Mechanical working of metals:
a—rolling; *b*—wire drawing; *c*—extruding; *d*—smith forging; *e*—closed-die forging; *f*—deep drawing (pressworking)

furnaces. The former are often of the reverberatory type, in which the heat is produced by the combustion of a liquid, solid or gaseous fuel. In the latter type, the heat is produced by electrical energy. Electric induction furnaces differ from resistance furnaces in that the heat is produced directly in the billet.

The main techniques by which metals are mechanically worked are rolling, drawing, extrusion, smith forging and closed-die forging.

Rolling (Fig. 4*a*). Rolled stock is produced by passing cold or heated metal through the revolving rolls of a rolling mill, as a result of which a change in shape, a reduction in cross-sectional area and increase in length of the billet occur.

The rolled products can be either finished parts (e.g., tubes, rails, beams), or stock for subsequent working by forging, stamping, machining, etc.

Drawing (Fig. 4*b*) is used for the production of wire of 0.01 to 6 mm diameter, sized bars and thin-walled tubes. In this technique, billets of the metal are cold-deformed by being drawn through a die hole of a diameter smaller than that of the cross section of the billet. The drawn parts have a smooth surface and accurate dimensions.

Extrusion (Fig. 4*c*). In this process, metal enclosed in a container is forced under pressure through a die, as a result of which sections are produced which correspond to the shape of the die. Extrusion is used for the manufacture of rods and complex sections which do not require finishing operations.

The process is carried out in horizontal hydraulic extrusion presses under pressures of the order of 6,000 to 10,000 tons.

Forging. This involves one of two techniques: smith forging and closed-die (drop) forging.

In smith forging, deformation of the metal occurs due to a blow delivered by a hammer, and the metal can flow only to the side along the surface of the flat dies. In closed-die forging, the metal assumes the shape of the die impression, into which it is forced by the blow.

In both smith and closed-die forging, a change in the shape and structure of the metal occurs. Blanks produced by forging are known as forgings.

Smith forging (Fig. 4*d*) comprises several basic operations: upsetting, drawing down, piercing, bending, cutting off, twisting and welding. The metal is hot-worked by forging hammers and in presses.

If the size and shape of a forging must approximate those of the finished article, closed-die forging is used. Here the metal is forced into the impression of a die. The latter is usually made of steel and has impressions in its surface in the shape of the forging to be made.

In closed-die forging, as opposed to smith forging, the expenditure of metal is drastically reduced, output is increased, and a considerably higher dimensional accuracy and surface finish are attained.

Closed-die forging may be either hot or cold. In either case the metal fills the three-dimensional die impression (Fig. 4*e*). An allied process, pressworking, deals with the cutting and forming of sheet metals (Fig. 4*f*). Closed-die forging is carried out by forging hammers, forging machines and presses, and pressworking, in presses.

The main defects, to which forging and other hot-worked billets are subject, are cracking, laminations (rupture of the metal), flaking, etc. Flakes have the appearance of white, distinctly outlined spots with a finely granular surface, which can be readily distinguished from the main background of the fracture by their colour.

Apart from the detection of defects due to their external appearance, special methods are used for the testing of billets, including micro- and macroscopic methods, X-ray analysis, magnetic methods, ultrasonic testing, etc.

Machining of Metals. Castings and forgings are seldom more than close approximations to the final shape of a manufactured article, and it is consequently necessary to obtain the shape and dimensions specified in drawing by machining, i.e., by removing extra stock in the form of chips.

Machining is carried out by means of various cutting tools mounted in metal-cutting machine tools such as lathes, milling machines, planers and shapers, grinders, etc.

Machining of the external and internal diameters of cylindrical workpieces is called turning and is carried out in lathes. These may be classified as centre, engine, turret, and facing lathes; vertical turning and boring mills; multitool single-spindle, multispindle automatic and semiautomatic lathes, etc.

The basic cutting tool in turning is the single-point tool. Various types of single-point tools are used for different jobs, such as straight turning, boring, facing, cut-off, threading, form tools, etc.

In lathes, the workpiece to be machined revolves, while the cutting tool is fed longitudinally or crosswise.

Making holes with drills, counterbores, countersinks and reamers is performed in upright, radial and horizontal drilling machines. In these machines, as a rule, the primary cutting motion (rotation) and axial feed are imparted to the

cutting tool (drill). In horizontal drilling machines, the workpiece revolves, while the tool is fed axially.

The surfaces of various parts, round or irregular, slots, keyways, gear teeth, etc., may be machined in milling machines of the horizontal, universal, vertical or keyway-milling types.

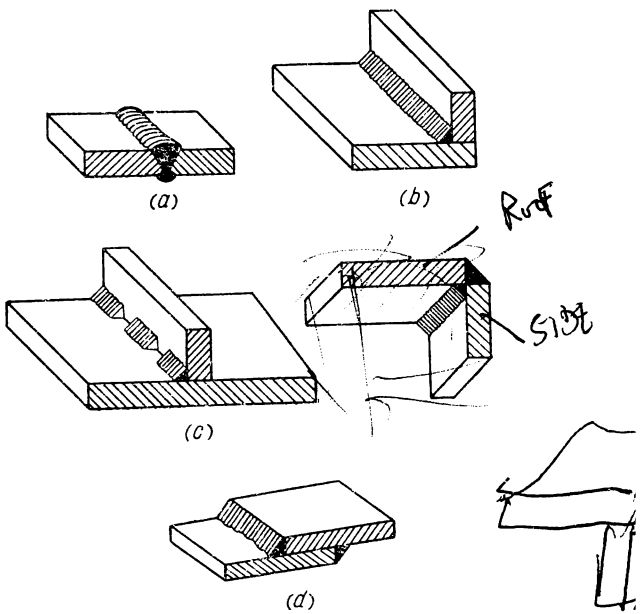


Fig. 5. Types of welded joints:
a—butt; *b*—corner; *c*—tee; *d*—lap

In milling, the cutter revolves while the workpiece is fed across it with the appropriate surface in contact. Depending on the type of job, plain, face, side and other milling cutters are used.

In planers and shapers, machining is performed by longitudinal travel of the workpiece (planer) or tool (shaper) and cross feed of the tool (planer) or workpiece (shaper).

Thread cutting is carried out with screw taps, threading dies, single-point tools, chasers and other tools.

Welding of Metals. Welding is a method of permanently joining metals and alloys.

The metal is heated either to its melting point or to a plastic state. Local melting of the parts to be welded is brought about by one of two forms of energy—chemical or electrical.

Chemical welding can be subdivided into forge, gas and thermit welding. Electric welding is subdivided into arc and resistance welding. Distinction is also made between welding by hand, semiautomatic and fully automatic welding.

According to the location of the parts to be welded, the joints produced can be classified as butt-, corner-, tee- or lap-joints (Fig. 5).

Defects may arise in the weld itself or the adjacent sections during welding. These can be pores, cracks, burned-through spots, dimensionally non-uniform joints, etc.

Bench Working of Metals. This is the shaping of metals in the cold state, performed mainly by hand with the aid of various cutting tools.

The term *bench work* embraces laying out, bending, straightening, cutting, hacksawing, filing, drilling, thread cutting with dies and taps, scraping, riveting, soldering, tinning, etc. In addition, fitters and repair hands (allied trades) may also be required to repair and assembly various machines and units, mechanisms and devices, to fit steam pipes and heating systems, as well as to lay water and gas mains and to do other plumbing jobs.

Various tools are used in this work: hammers, chisels, files, scrapers, screw drivers, wrenches, hacksaws, drills, screw taps and dies, soldering irons, etc.

Bench hands and fitters must have wide experience, i.e., they must be able to use a variety of tools and carry out various operations, which may differ in complexity and accuracy.

CHAPTER

2

Reading drawings

2-1. DRAWINGS AND SKETCHES

The engineer expresses his designs in the form of graphical representations of a machine, assemblies or components, which are called *drawings.* In order that all technicians should be able to understand the designs produced by an engineer and carry out his intentions, drawings must be constructed in accordance with definite, generally accepted rules and a system of conventional notations as laid down in the standards. If the basic rules for constructing drawings are known, a drawing can be correctly read and executed.

Sketches are rough drawings made by hand. Sketches are used as the basis for making working drawings, or as direct instructions for the manufacture of parts. It is necessary to indicate in a sketch all the data of the corresponding drawing.

The most important drawings used in industry are *working drawings.* A working drawing should enable the worker to reproduce the engineer's specifications as to the shape, dimensions and surface finish of the article required.

In designing new machines, the first step is to work out and draw a scheme of the machine. This gives a general idea of the functioning of the machine, and is called a *draft project drawing.* From the draft project drawing, drawings of the general views and assembly drawings are prepared, which are called *technical project drawings.* From these, the working drawings are developed.

The working drawings must contain:

(1) the required projections, views and sections which characterize the shape of the components;

(2) all dimensions required for the manufacture of the components;

(3) dimensional or fit tolerances denoted by letters, or the standard of accuracy according to which free dimensions are executed;

(4) symbols indicating the surface finish of the components;

(5) an indication of the machining required after assembly or during assembly of a given component with others;

(6) special indications as to the machining of individual surfaces, e.g., those of threads, gear teeth, etc.;

(7) an indication of the heat treatment;

(8) an indication of the material of which the component is to be made;

(9) an indication of the hardness of the material of the blank and of the finished component;

(10) an indication of the number of given components in one article;

(11) specifications in which any particular requirements are stipulated, e.g., parallelism of certain surfaces, any tapers, permissible out-of-roundness, etc., details of any specific treatment, hardening, etc.

2-2. METHODS OF REPRESENTATION IN DRAWINGS

The representation of components, assemblies or machines on drawings should be carried out by orthographic projection.

An orthographic projection may be constructed by placing the part against a plane of projection, and drawing lines through definite points of the part, perpendicular to the plane of projection. By joining the points of intersection of these lines with the plane, the projection of the part on the plane is obtained.

Figure 6 illustrates the projection of a figure on a plane. Straight lines, perpendicular to the plane, are drawn through the points A, B, C, D and E. By joining the points a, b, c, d, e in the projection plane, the projection of the shape is obtained.

In dealing with three-dimensional parts, a single projection does not always give a full picture. The part may therefore be rendered in 2, 3, 4, 5 or 6 projections. It is

assumed that the part is always situated between the observer and the plane on to which it is projected.

Let us imagine that the part is at the centre of a cube and is to be projected on to each face of the cube. By unfolding the cube and spreading it in one plane, we obtain the development of these six planes of projection. The projections of the part thereon are shown in Fig. 7. Face *1* shows the frontal elevation, which is taken as the main projection

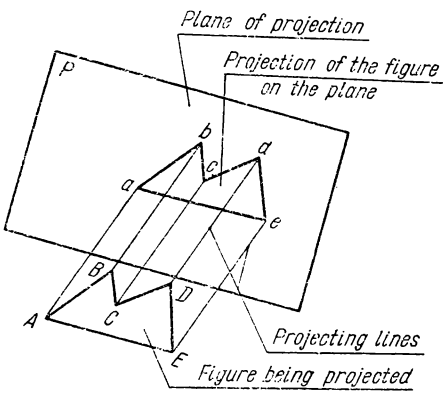


Fig. 6. Projection of a figure on a plane

on which the part must be drawn as it functions in an assembly. This is the front view. The picture in face *2* is the top view, that in face *3* is the side view from the left, that in face *4* is the side view from the right, that in face *5* is the bottom view and that in face *6*, the rear view.

If the part is of complex shape and the dimensions and shapes of individual inclined surfaces appear distorted when projected on to the main planes of the projection, then a projection on to an additional plane is made, the latter being parallel to the inclined surfaces in question. Such projections are called auxiliary views. On the drawing they are denoted by the inscription "View A" and by arrows showing from which direction they are taken.

To draw very large and very small components to the same scale or full-sized on one drawing is not always convenient. The drawing should therefore be scaled up or down

uniformly, to preserve the relative dimensions of the components with respect to their natural size.

The *scale* is the ratio between the linear dimensions of the representation of an object on a drawing and the actual dimensions of the object itself. In accordance with the State Standards of the Soviet Union, the following denotations

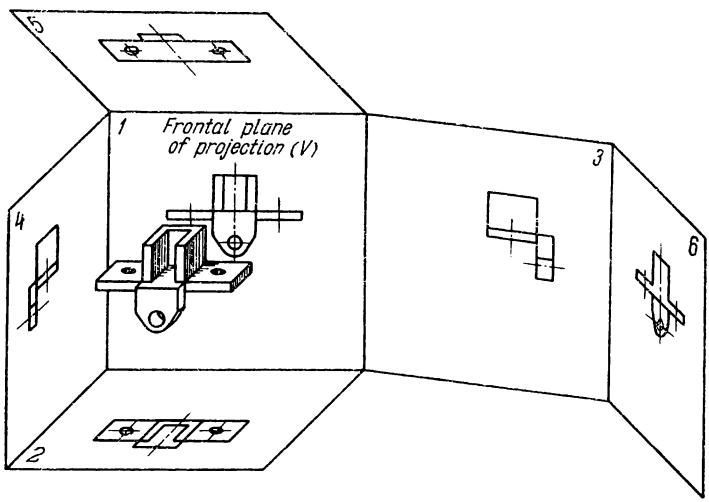


Fig. 7. Projection of a part on six planes

of the scale of drawings have been adopted: M1:1; M1:2; M2:1, etc., where M means scale; the first numeral (numerator) denotes the magnitude of a certain dimension on the drawing; the second numeral (denominator) is the corresponding actual dimension of the object on the drawing.

Thus the notation M1:2 indicates that the dimensions in the drawing are one half as large as the corresponding actual dimensions; M2:1 means that dimensions in the drawing are twice as large.

Below are given the scales adopted in the standards.

Reduction scales: 1:2; (1:2.5); (1:4); 1:5; 1:10; (1:15); 1:20; 1:25; 1:50; (1:75); 1:100, etc.

Scales larger than full size: 2:1; (2.5:1); 5:1; 10:1; 20 : 1, etc. The scales shown in brackets are not recommended.

2-3. LINES ON DRAWINGS

Each line on a drawing has a specific function. Solid heavy lines show the visible outlines of an object. They are, as it were, the main lines of the drawing. Lines of lesser thickness, dash, dot-and-dash and other lines show the

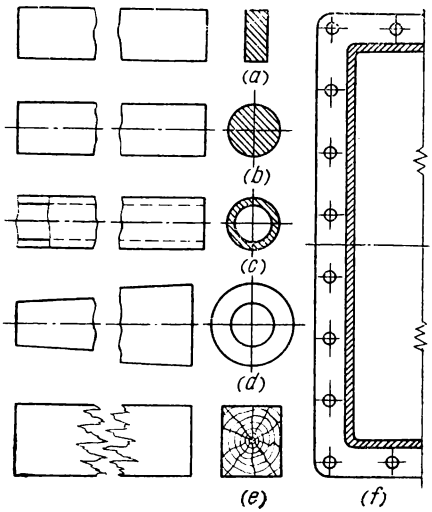


Fig. 8. Break lines:
a, *b*, *c*, *d*—metal; *e*—wood; *f*—long break

invisible contours, axes of bodies of revolution, centres of circles, etc. There are also dimensional lines, shaded sectional views and cross sections.

The types of lines and their functions are laid down in the Standards (Table 1).

Table 1

Lines on Drawings

Name	Sample	Thickness ratio	Purpose
Solid main line	———	*b*	Visible outlines. Transition lines. Outlines of revolved and removed sections. Item number lines, or "balloons"

Continuation

Name	Sample	Thickness ratio	Purpose
Solid thin line		$b/3$	Dimensional and extension lines. Shading lines. Leaders. Zone boundaries of surfaces of different dimensional accuracies and/or surface finish
Solid wavy line		$b/2$ or less	Breaks and lines separating sections from the views
Dash line		From $b/2$ to $b/3$	Hidden outlines and transition lines
Broken line		From b to $1\frac{1}{2}\ b$	Section lines
Dot-and-dash line		$b/3$ or less	Axial and centre lines
Heavy dot-and-dash line		From $b/2$ to $b/3$	Zone boundaries between surfaces with different heat treatment. Lines for the representation of a mechanism or its individual parts in the extreme or intermediate position

The thickness of the main outlines of views, cross sections and cut-away views must be identical; it is denoted by the letter *b* and is between 0.6 and 1.5 mm.

Breaks are drawn as shown in Fig. 8.

2-4. DIMENSIONING, SPECIFYING GEOMETRICAL FEATURES AND SURFACE FINISH ON DRAWINGS

In a working drawing, dimensions are written only on the visible outlines of a component; no dimensions are marked on invisible outlines represented by dash lines.

Dimensions relating to the same detail of a component (e.g., keyways, recesses, etc.) are indicated on the projection in which this detail appears most clearly.

It is understood that all dimensions are given in millimetres; the sign mm is therefore omitted. Hence, only if the dimensions are given in centimetres, decimetres or metres, are the unit signs placed next to the number, e.g., 3 m; 5 dm.

Dimensions of angles, in degrees, are written between extension lines which are continuations of the sides of the angle.

Cylindrical external and internal surfaces are indicated by the diameter sign, ∅ (Fig. 9).

For the indication of the permissible lack of concentricity of two or several diameters, the sign shown in Fig. 10 is used. The requirements for parallelism of planes and perpendicularity of end faces, etc., to other surfaces or axes are indicated similarly.

Specifications as to surface finish are indicated on a drawing by equilateral triangles. An apex of the triangle is placed on the corresponding surface of the part (Fig. 11). On the right of the triangle, the class of finish is indicated by a number (there are 14 altogether), e.g., ▽ 3, ▽ 10.

A surface, the finish of which is less than first class, i.e., one in which the height of the irregularities exceeds 320 μ (microns), is indicated by the sign $\sqrt{}$. Above this sign, the permissible roughness is marked in microns. For instance, the sign $\overset{400}{\sqrt{}}$ allows roughness up to 400 μ.

To identify those surfaces on a drawing which are not to be machined, the sign ∾ is used.

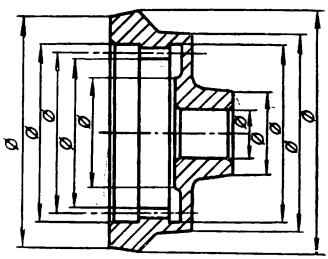


Fig. 9. Specifying diameters on a drawing

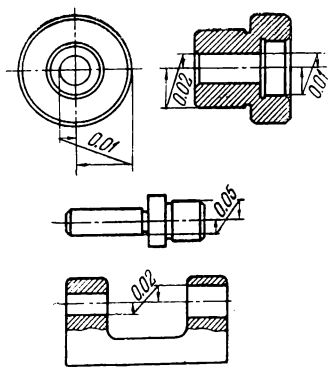


Fig. 10. Concentricity symbols

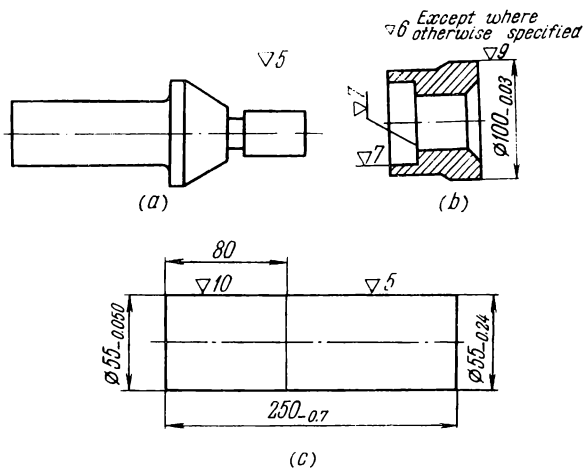


Fig. 11. Surface finish symbols:
a—common for all surfaces; *b*—on surfaces of different surface finish; *c*—on portions of different finish on the same surface

Signs for the degree of finish are placed on the outlines of the visible surface or on extension lines. If the finish of all surfaces of the part is to be identical, then the common sign and class of finish are indicated in the right-hand upper corner of the drawing (Fig. 11*a*).

In the drawing of a part, several surfaces of which are to have the same class of finish while only one or two are to have a different class, the finish of the similar surfaces is specified in the upper right-hand corner. The separate symbols for the remaining surfaces are then placed adjacent to the latter (Fig. 11*b*).

In the case when different portions of the same surface of a part require a different class of finish, these portions are separated by a light line and are marked for finish and dimensions separately.

2-5. REVOLVED AND REMOVED SECTIONS

In drawing the outlines of a part, it is not always possible to show all important details sufficiently clearly. In such a case, the method of sectioning is used.

A *section* is a drawing obtained by imaginary dissection of an object by one, or several, planes.

Sectioning is always performed in a normal transverse plane.

Distinction is made between *removed* and *revolved* sections. A revolved section is superimposed over that area of the component through which the sectional plane passes (Fig. 12*a*). Removed sections are placed outside the contours of the component (Fig. 12*b*).

Wherever the object has been cut by the section plane the cut surface is indicated by section lining, also called crosshatching, done with fine lines, generally at 45° and uniformly spaced.

Sometimes the section line of the component is represented by a heavy dash line extending between two capital letters and marked with arrowheads indicating the direction of the view (Fig. 12*c*). When the section line coincides with the axis of symmetry of the removed or revolved section, the section line is indicated by a dash-and-dot line without letters and arrowheads (Fig. 12*b*).

For sections through a rib disposed at an angle, the sectional view can be turned accordingly. In such a case, the word "Turned" is added to the inscription (Fig. 12*d*). If there

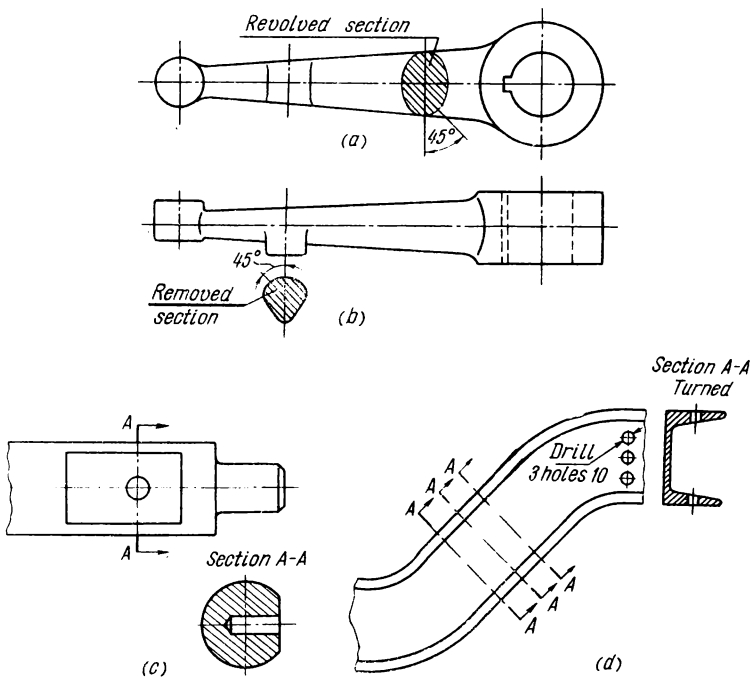


Fig. 12. Sections:
a—revolved section; *b*—removed section; *c*—removed section with arrows; *d*—across an inclined web

are several identical sections where the cutting planes are set at different angles, the word "Turned" is not added to the inscription.

2-6. OTHER SECTIONAL VIEWS

In addition to removed and revolved sections, other sectional views are used to clarify a drawing and to show the invisible internal outlines of objects.

A *sectional view*, or *section*, is the conventional drawing of that portion of an object dissected by an imaginary plane,

which would be visible if the portion of the article between the eye of the observer and the cutting plane were to be removed. The section shows what there is in the cutting plane and behind it (Fig. 13).

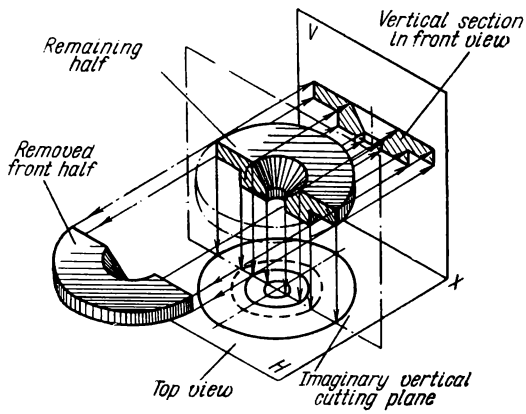


Fig. 13. Sectional view

Distinction should be made between vertical, horizontal and oblique sections. In *vertical sections*, the cutting plane is perpendicular to the horizontal plane of projection (Fig. 14*a*

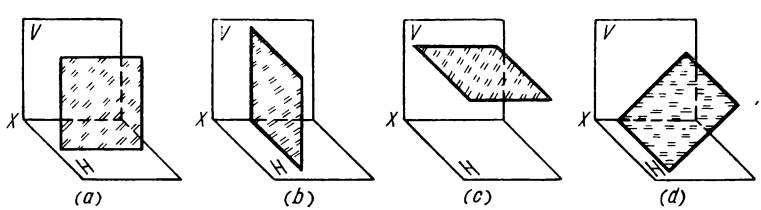


Fig. 14. Methods of making sectional views:
a—vertical frontal section; *b*—vertical profile section; *c*—horizontal section; *d*—oblique section

and *b*), in *horizontal sections* the cutting plane is parallel to the horizontal plane of projection (Fig. 14*c*), and in *oblique* ones, the cutting plane makes an oblique angle with the horizontal plane of projection (Fig. 14*d*).

If the cutting plane is parallel to the frontal plane of projection, then the section is *frontal* (Fig. 14*a*); if it is parallel to the profile plane, the section is *profile* (Fig. 14*b*).

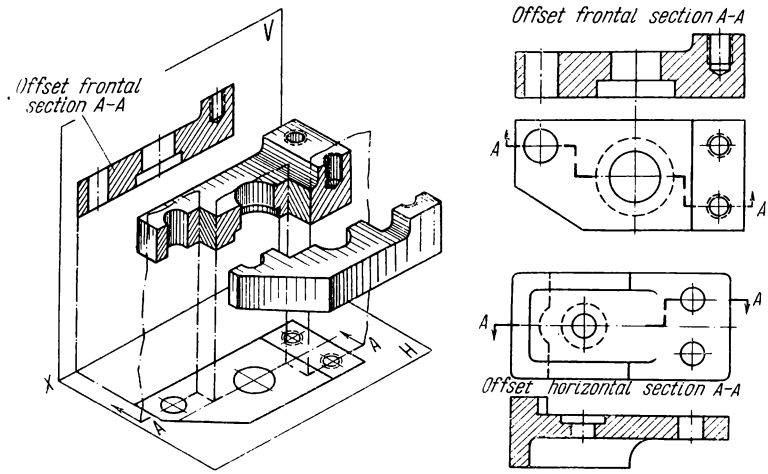


Fig. 15. Offset frontal and horizontal sections

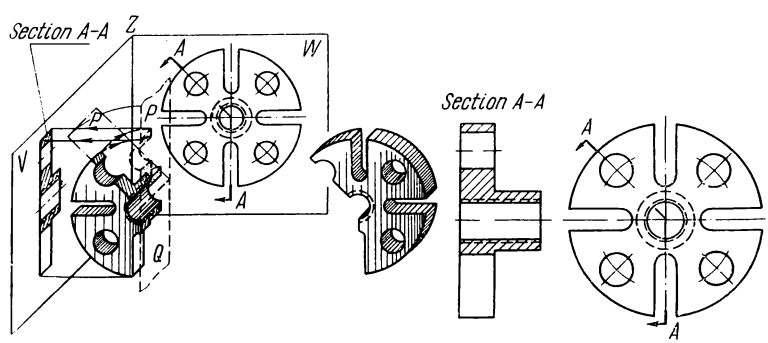


Fig. 16. Broken-out profile section

Horizontal and vertical sections can be placed in areas of the drawing corresponding to the views themselves, or they can be taken out separately, the direction of viewing by the observer being indicated by arrowheads and letters.

Depending upon the number of cutting planes, sectional views are classified as *simple* (with one cutting plane) and *complex* (with two or more cutting planes).

A complex section obtained with the aid of parallel cutting planes is called an *offset section* (Fig. 15), while it is a *broken section* (Fig. 16) if the two cutting planes intersect each other.

A section which does not reach the axis of symmetry of the component is called a *broken-out section.*

In drawing a simple or complex section, when the cutting plane passes through the axis of or along a long rib, spoke, disk or thin wall, these portions appear in the section, but they are divided from the remaining part of the component by a separate line and are not crosshatched.

2-7. REPRESENTATION OF SCREW THREADS AND GEARS

Screw Threads. Threads are divided into two groups—fastening screw and power screw threads.

Fastening screw threads are used for joining two or more components, whereas *power screw* threads are used for the transmission of power in mechanisms. Metric, English and pipe threads are fastening screw threads.

Metric thread is made in the U.S.S.R. according to the corresponding standard (Fig. 17*a*). It has the profile of an equilateral triangle with an apex angle of 60°, and the distance between adjacent apexes of the thread, i.e., the pitch, is measured in millimetres.

English thread is characterized by the number of threads (turns) contained within a length of one inch (25.4 mm). The profile of the thread is represented by isosceles triangles with apex angles of 55° (Fig. 17*b*).

Pipe thread has a profile rounded at the apex (Fig. 17*c*) and is shallow in depth, which enables it to be cut on thin-walled articles; it is used where tight joints are required.

Power screw threads are used to provide the drive to tool rests, carriages, tables and other moving parts of various machine tools. The types of power screw threads (trapezoidal, square, etc.) are shown in Fig. 17*d*, *e*, *f* and *g*.

When required, the profile of the thread can be shown in cross section, or else it is drawn separately. On the thread

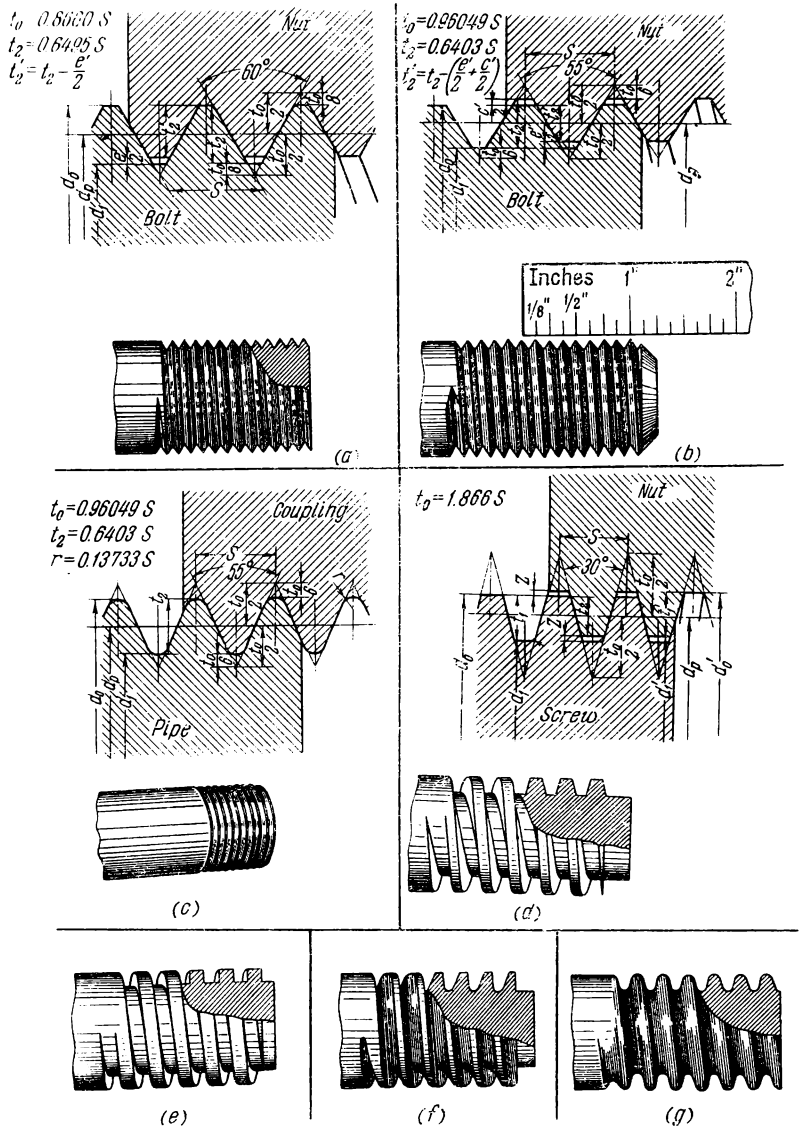


Fig. 17. Types of thread:

metric; *b*—English; *c*—pipe; *d*—trapezoidal; *e*—square; *f*—buttress; *g*—round

drawing, the type required is indicated by a letter code: М—metric, Труб.—pipe, КТруб.—taper pipe, Трап.—trapezoidal and Уп.—buttress.

Numerals following the letters show the diameter, and, preceded by a multiplication sign, the pitch of the thread. For instance, a metric thread of 24 mm diameter and 2 mm

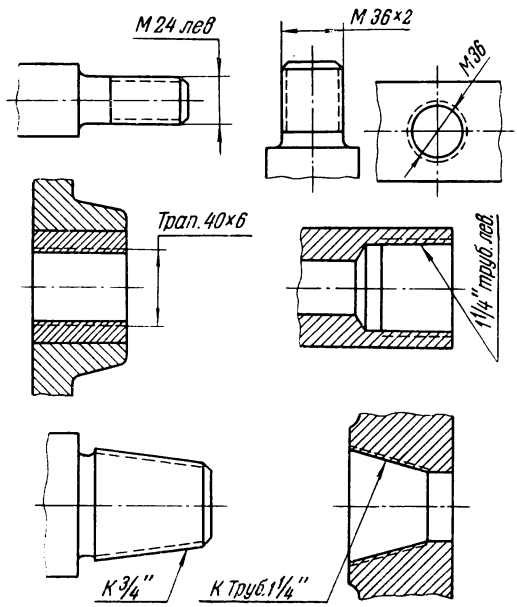


Fig. 18. Thread specification

pitch is denoted by M24 × 2. In addition, the class of accuracy of the thread is indicated, and if the thread is left-handed, then the designation «лев» is appended.

For instance, Трап. 40 × 6 лев means that the thread is trapezoidal, single-start, has a major diameter of 40 mm, a pitch of 6 mm, and is left-handed.

For English threads, only the major diameter in inches is indicated, e.g., 1″ means that the thread is an English thread 1″ in diameter. Taper and straight pipe thread is designated by the nominal inside diameter of the pipe on which it is to be cut. Thus, Труб. 1″ specifies the straight

pipe thread of 1″ pipe. The thread size on drawings is shown as in Fig. 18.

Gears. The elements of toothed gears and examples of drawings thereof are given in Fig. 19*a*.

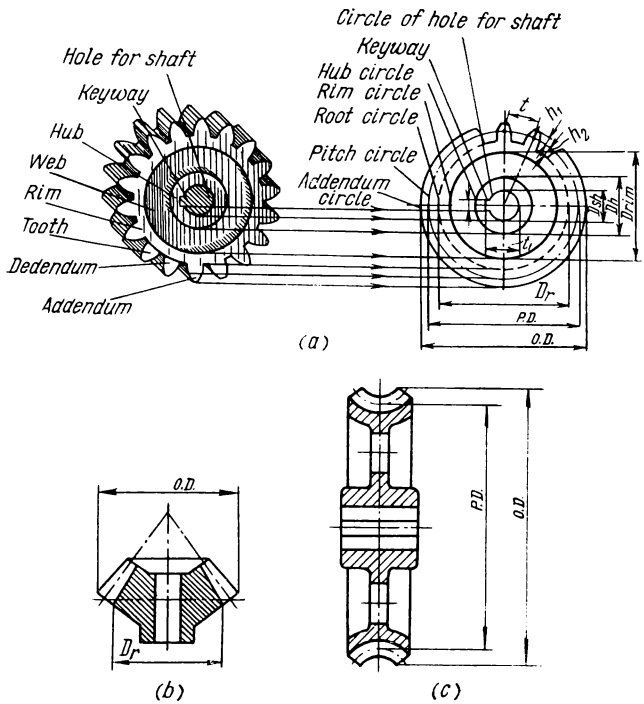


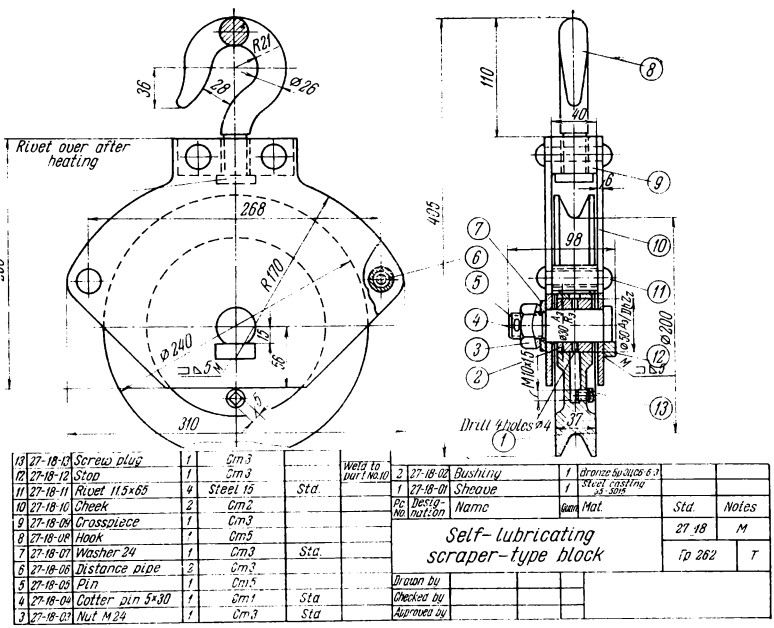
Fig. 19. Gear drawings:
a—spur; *b*—bevel; c—worm wheel

The circumference at the outside diameter of a gear is shown by a continuous line. The conventional circumference which divides the tooth profile into face and flank is called the pitch circle.

Depending on their type, gears are divided into spur, bevel, worm and helical gears. The first three of these are shown in Fig. 19*a*, *b* and *c*. Helical gears are similar to spur gears except that the teeth are arranged along right- or left-hand helixes.

2-8. ASSEMBLY DRAWINGS

In an assembly drawing (Fig. 20), part or the whole of the component is rendered in the required number of views with the necessary sections. The overall dimensions and



13	27-18-13	Screw plug	1	Cm 3		Weld to part No.10	2	27-18-02	Bushing	1	bronze Sp.-Sn.Zn6 6-3
12	27-18-12	Stop	1	Cm 3			1	27-18-01	Sheave	1	steel casting 35 GOST
11	27-18-11	Rivet 11.5×65	4	Steel 15	Std.		Pos.	Designation	Name	Mat.	Std.	Notes
10	27-18-10	Cheek	2	Cm 2					Self-lubricating scraper-type block		27.18	M
9	27-18-09	Crosspiece	1	Cm 3							Tp 262	T
8	27-18-08	Hook	1	Cm 5								
7	27-18-07	Washer 24	1	Cm 3	Std.							
6	27-18-06	Distance pipe	2	Cm 3								
5	27-18-05	Pin	1	Cm 5								
4	27-18-04	Cotter pin 5×30	1	Cm 1	Std.							
3	27-18-03	Nut M 24	1	Cm 3	Std.							

Fig. 20. Assembly drawing

fits of mating surfaces are shown, and instructions are given as to the machining, etc., of the components during assembly. The assembly of components can be carried out by welding. Welded joints made by electric-arc welding are denoted in drawings by the letter Э, those produced by gas welding by Г, those made by resistance welding by КТ, and shielded-arc welding by З.

The location of the welded joint is indicated by a symbol resembling an arrow on whose shaft are placed the conventional symbols for the weld and the method of welding. The symbol for visible joints is put above the shaft, and that for invisible ones, below the shaft.

The components in assembly drawings have reference numbers or conventional designations. These are written on the shelf of a leader, or enclosed in a circle with a leader pointing to the corresponding component.

Any particular requirements—manufacturing specifications—for a unit or manufactured article are set down in the right-hand corner of the assembly drawing. These include the prescribed methods of checking and testing, instructions for marking, for anticorrosive or decorative coatings, for adjustment, regulation, packing, storage, handling, etc.

In the right-hand lower corner of the drawing, the title block, or box, is located, and above it, the bill of material (or list of components) is given. The latter indicates the reference numbers of all the components in order, their conventional designations, names, the quantity of each component in the assembly or article, the material of which the components are made, and any remarks.

Assembly drawings are read in the same way as working drawings, i.e., the views must be studied first, and then how the components are fitted together, taking into account the dimensions and other requirements.

2-9. GRAPHICAL SYMBOLS OF MACHINE PARTS AND UNITS USED IN DIAGRAMS

In many cases, drawings are made, not to show the construction of the components and units of a machine, but only to indicate the principles of operation and transmission of motion to individual components or units. Such drawings are called *kinematic* or *gearing diagrams.*

In gearing diagrams the types of motion, the components and units are denoted by various conventional symbols, as shown in Fig. 21 (according to the U.S.S.R. standard).

Type of motion:

1—rectilinear in one direction;

2—shaft, spindle, axle, rod, etc.;

3—fixed guiding element for a reciprocating rod.

Plain and antifriction bearings for shafts:

1—general symbol;

2—radial ball bearings;

6—single-direction ball thrust bearings.

Plain and antifriction step bearings:

7—general symbol.

Parts mounted on shafts:

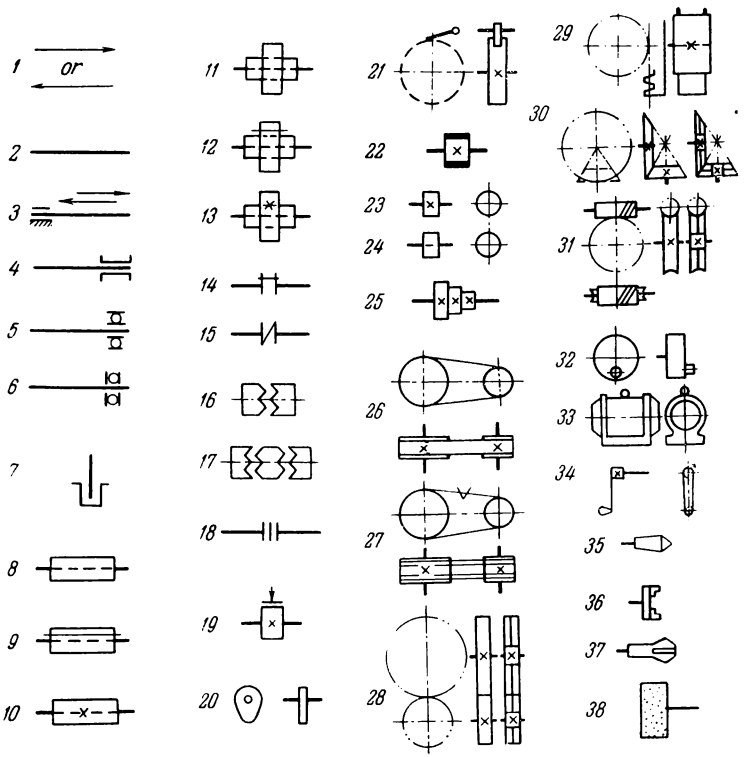


Fig. 21. Graphical symbols used in kinematic diagrams

8—freely mounted;

9—sliding on a feather;

10—fixed on a key.

One part mounted on another:

11—freely mounted;

12—sliding on a feather;

13—fixed on a key.

Coupling between two shafts:

14—rigid coupling;

15 flexible coupling.

Jaw clutches:

16 one-sided;

17 twin.

Friction clutches:

18 —general symbol.

Other devices:

19—shoe brake;

20—plate cam;

21—ratchet gearing;

22—flywheel on shaft.

Pulleys:

23—working pulley on shaft;

24—idle pulley;

25—step pulley.

Belt drives:

26—open flat belt drive;

27—V-belt drive.

Gearing:

28—external spur gearing (general symbol);

29—rack and pinion gearing (general symbol);

30—bevel gearing (general symbol);

31—worm gearing (general symbol).

Other elements:

32—eccentric cam;

33—electric motor;

34—crank handle.

Spindle noses of the following types of metal-cutting machine tools:

35—centre type (work held between centres);

36—chuck type (work held in a chuck);

37—bar type (bar stock held in a collet chuck);

38—grinding machines.

Apart from gearing diagrams, there are hydraulic system diagrams of machine tools and various mechanisms, in which the transmission of motion is brought about by hydraulic devices. Hydraulic system diagrams trace the flow of the liquid under the action of various types of hydraulic pumps.

The diagram of the hydraulic system of a grinding machine will be considered in Chapter 7.

2-10. RULES FOR READING DRAWINGS

Drawings are read in a definite sequence in four stages:

(1) Study of graphical views and sections of the components. Studying the continuous and dash lines, as well as the features of the part in order to get a clear idea of its external and internal shape.

(2) Studying the dimensions, tolerances and surface finish symbols of the component.

(3) Studying and analyzing the manufacturing specifications and other requirements for the part.

(4) Noting the material, quantity, weight and other information shown in the title of the drawing.

2-11. TAKING MEASUREMENTS

To draw sketches and drawings of finished parts, the latter must first be measured, i.e., their dimensions must be determined by means of measuring tools.

For the measurement of parts, a steel rule, outside calipers, inside calipers and bevel protractor are used. More accurate measurements are made with vernier calipers, micrometer calipers, rod gauges, inside micrometers, dial comparators and other tools and instruments.

In the measurement of external and internal surfaces with vernier calipers, an accuracy of 0.1 mm to 0.02 mm can be attained.

The micrometer caliper can measure parts with an accuracy up to 0.01 mm.

For a more detailed account of measuring tools and methods, see Chapter 4.

Measurement and dimensioning are carried out from location and measuring datum surfaces. The surface of a part from which it is located in machining in reference to the cutting tool is called the *location datum surface*, and that from which measurements are carried out, the *measuring datum surface*. To ensure the highest accuracy in the manufacture of parts, it is desirable that the same surface be used both for location and measuring.

CHAPTER

3

Tolerances and fits

3-1. INTERCHANGEABILITY OF PARTS

Each machine, device or mechanism consists of assembled units and parts which are joined by various methods. During assembly, the parts are sometimes additionally machined to ensure that they exactly fit their mating parts. The more accurately the parts are made, the less fitting is required.

Some machine parts wear out rapidly and must be replaced frequently. The replacement of parts may also be necessary due to breakage or for other reasons.

Parts and units of machines, manufactured with such accuracy that they can be installed without further individual fitting, are referred to as interchangeable. Part interchangeability is a fundamental requirement of not only mass production, but of other types as well.

Interchangeability provides a number of advantages in the manufacture, operation and maintenance of machines, namely:

(1) the machining time of the parts is reduced, as well as manufacturing costs, due to the use of special or specialized jigs and fixtures (universal change-over fixtures or universal standard built-up fixtures). This makes it possible to set up lot production;

(2) the assembling time is reduced, as is the required floor space of the assembly shops, and conditions are provided for the mechanization and automation of assembly processes;

(3) machine repair becomes simpler and cheaper;

(4) various plants can cooperate in manufacturing the parts for a single machine.

Standards are established whose observance ensures part interchangeability.

Intraplant standardization is the establishment of common norms and requirements throughout a plant as regards the types, grades, dimensions and quality of the manufactured articles. Such standardization may concern a single plant or all the enterprises of some branch of industry.

National standardization establishes the level of norms and requirements for the physical and dimensional factors, raw materials and mass-produced articles with reference to their unified dimensions and interchangeability. Standardization takes the form of state standards and embraces the production of the whole country.

3-2. MACHINING ACCURACY

In connection with the manufacture of articles, the term "accuracy" is used to mean the degree to which the actual dimensions and shape of the finished article approach those specified by the drawing. Interchangeable parts must show the least possible dimensional deviations.

The degree of machining accuracy of a part is determined by the requirements made to its individual surfaces. For instance, in a gear, the external cylindrical surface does not contact the root circle of the mating gear, and therefore there is no necessity for it to be particularly accurately machined. The bore of a gear, however, since it fits tightly on the shaft, must be machined with greater accuracy. The diameter of the shaft journals, on which the bearings are fitted, must also be machined to a high degree of accuracy.

Thus, the accuracy with which parts are machined wholly determines their interchangeability and suitability for application in a particular machine assembly.

3-3. NOMINAL, ACTUAL AND LIMITING SIZES

Mating Parts

Two parts, fitted together with a fixed or movable joint, are called *mating parts*. The dimensions of the surfaces that are in contact when mating parts are assembled are called *mating dimensions*, and those along which contact

not made, *free dimensions.* For instance, the internal diameter of a grinding wheel and the diameter of the sleeve on which the wheel is installed are mating dimensions. The external diameter and the face width of a gear are free dimensions.

One of the mating parts always envelops the other, and hence in the joining of parts one distinguishes between an enveloped and an enveloping part. In the fitting of a shaft with a bushing, the shaft is the enveloped and the bushing the enveloping part.

Of two mating parts, the enveloped part is conventionally called the shaft and the enveloping one, the hole. For instance, when bearings are mounted on a spindle, the spindle is the shaft and the bearing is the hole. In the fitting of a keyway on a shaft with a key, the key is the shaft and the keyway is the hole.

Nominal Size. In designing mating parts, the common dimension of the two adjoining surfaces is determined. This dimension is called the *nominal size.* The nominal sizes of parts are determined from available sizes of cutting tools (drills, taps, reamers, etc.), the most common standard sizes of bearings, bolts, etc.

This requirement has led to the establishment of standard preferred series of nominal diameters and lengths. These series represent geometrical progressions, i.e., each term in the series (except for the first) is derived from that preceding it by multiplying the latter by a constant number, known as the *ratio of the progression.* The following ratios of progression are used: $\sqrt[5]{10}$, $\sqrt[10]{10}$, $\sqrt[20]{10}$ and $\sqrt[40]{10}$.

According to the corresponding U.S.S.R. standard, there are 4 series of standard preferred sizes: Ra5, Ra10, Ra20, Ra40. For instance, series Ra40 consists of the following preferred sizes (in mm): 1.0, 1.05, 1.1, 1.15, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.4, 2.5, 2.6, 2.8, 3.2, 3.4, 3.6, 3.8, 4.0, 4.2, 4.5, 4.8, 5.0, 5.2, 5.5, 6.0, 6.3, 6.5, 7.0, 7.5, 8.0, 8.5, 9.0 and 9.5.

By shifting the decimal point one or more places to the right or to the left, new series of sizes, larger or smaller, respectively, are obtained in the range from 0.001 mm to 10,000 mm, for instance, 10, 10.5, 11, 11.5, 12, 13, 14, etc., or 0.1, 0.105, 0.110, 0.115, etc.

The sizes of an article as calculated by the designer should be rounded off to the nearest corresponding dimension of the normal preferred series. Interoperational sizes, i.e., dimensions of components with allowance for subsequent machining, are not to be rounded off.

Actual and Limiting Sizes. Apart from the nominal sizes of parts, there are actual and limiting sizes.

The *actual size* is that obtained in measuring a finished part with the maximum accuracy attainable in the given production conditions.

In assembly, the actual sizes of the shaft and hole must ensure the required fit, and thus the actual sizes must lie within narrow limits.

Limiting sizes, or *limits of size*, are the maximum and minimum values between which the actual size may vary, thus ensuring the required accuracy of the fit of the parts.

For instance, if a shaft diameter is indicated as ∅ 20 ± 0.1 mm, then ∅ 20 mm is the nominal size, ∅ 20.1 mm the maximum limit and ∅ 19.9 mm the minimum limit, i.e., if the actual diameter of the part is between ∅ 19.9 mm and ∅ 20.1 mm, the required fit will be obtained.

In reference books, upper and lower deviations are usually listed, the upper deviation being the difference between the largest permissible and the nominal sizes; and the lower deviation, the difference between the smallest permissible and the nominal sizes. In the above example, the upper deviation is 20.1 — 20 = 0.1 mm and the lower 19.9 — 20.0 = —0.1 mm.

3-4. TOLERANCES

The difference between the maximum and minimum limits of size is called the *tolerance* on the size of the part. It shows the limits within which the size of a part may vary.

For instance, in the machining of a shaft of $\varnothing\ 40\ ^{+0.027}_{-0.037}$ mm,

∅ 40 mm is the nominal diameter;
∅ 40.027 mm is the maximum limit of size;
∅ 39.963 mm is the minimum limit of size;
+ 0.027 mm is the upper deviation from the nominal size;
—0.037 mm is the lower deviation from the nominal size.

The tolerance is calculated as follows:

(1) $40.027 - 39.963 = 0.064$ mm, or

(2) $0.027 - (-0.037) = 0.027 + 0.037 = 0.064$ mm.

The actual diameter of the shaft must be between 39.963 mm and 40.027 mm.

A dimensional tolerance is always a positive value, but deviations may be either positive, or equal to zero, or negative.

The difference between the maximum and minimum limits of size is called the *tolerance zone.*

3-5. CLEARANCES AND INTERFERENCES

Clearances. When the diameter of the hole is greater than that of the shaft, the latter will fit freely into the former, since there will be a clearance between them.

Clearance is a positive difference between the diameter of the hole and that of the shaft. When several identical parts (shafts and holes) have the same nominal size and tolerances, it is possible, because of the tolerances, that the clearances vary somewhat when the sets of mating parts are assembled.

The largest clearance will be obtained in a fit when the hole has been machined to the maximum limit of size and the shaft to the minimum limit. The clearance will be the least when the hole is machined to the minimum limit of size and the shaft to the maximum limit.

For instance, if the specified shaft diameter of an assembly is $45_{-0.017}$ mm and the hole diameter is $45^{+0.150}_{+0.032}$ mm, the limits of size will be:

(a) for the shaft, ∅ 45.000 mm maximum, ∅ 44.983 mm minimum;

(b) for the hole, ∅ 45.150 mm maximum, ∅ 45.032 mm minimum.

The maximum clearance will be $45.150 - 44.983 = 0.167$ mm, and the minimum, $45.032 - 45.000 = 0.032$ mm.

Interference. When a fixed fit between the shaft and hole is required in an assembly, the shaft is made somewhat larger than the hole. This difference in dimensions is termed the interference, in other words, *interference* is a negative

difference between the diameter of the hole and that of the shaft.

Maximum interference is obtained when the shaft diameter is machined to its maximum limit of size and the hole diameter to its minimum limit. Minimum interference will result from the reverse conditions.

For instance, when the shaft diameter is $45_{-0.017}$ mm and the hole diameter $45\ ^{-0.025}_{-0.050}$ mm, the limits of size will be:

(a) for the shaft, ∅ 45.000 mm maximum, ∅ 44.983 mm minimum;

(b) for the hole, ∅ 44.975 mm maximum, ∅ 44.950 mm minimum.

The maximum interference will be $44.950 - 45.000 = -0.050$ mm, and the minimum, $44.975 - 44.983 = -0.008$ mm.

3-6. FITS

The nature of the joint, or association, obtained between two mating parts is characterized by the term *fit* by which is meant the degree of tightness or freedom for relative movement between the parts. According to their purpose, there are fixed fits and movable fits.

Movable fits are characterized by the clearance and are usually called clearance fits. The greater the clearance, the more easily one part will move relative to the other.

Fixed fits can be classified as interference and transition fits. Interference fits render the parts fixed relative to each other, since the shaft is forced into the hole under considerable pressure (prior to this assembly, the diameter of the shaft is somewhat greater than that of the hole).

Transition fits ensure proper location of shafts in holes and provide fixed joints only with the aid of additional fastening elements. Hence, the shaft diameter may be somewhat larger, equal to, or even smaller, than the hole diameter, i.e., in these assemblies there may be a clearance in some cases and an interference in others. In the case of small clearances, or interferences, a great accuracy is

attained in the alignment of the hole and shaft axes. Thus, transition and interference fits ensure coaxiality between the shaft and hole. Fig. 22 shows the combination of shaft and hole sizes required to obtain various fits:

I—the diameter of the hole is greater than that of the shaft. Such an assembly ensures a clearance fit. In this case, the tolerance zones of the hole and shaft do not overlap, the former being the larger for all values.

II—the difference between the bore and shaft diameters can result in a small clearance or interference. This will

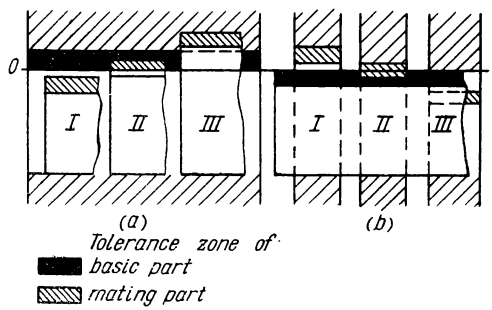


Fig. 22. Systems of fits:
a—basic-hole system; *b*—basic-shaft system

then be a transition fit. The tolerance zones of the hole and shaft partly or completely overlap.

III—the diameter of the shaft is greater than that of the hole. In this case, interference fits are obtained in assembly. The tolerance zone of the shaft is above that of the hole, i.e., interference is guaranteed for any actual shaft and hole sizes.

Both clearance and fixed fits can be made with clearances and interferences of various magnitudes. For instance, in the rotation of the spindle of a grinding machine in its bearings, the clearance must be less, and hence the fit must be tighter, than that used for mounting the grinding wheel on the wheel sleeve.

According to the U.S.S.R. standard, the following fits are used in Soviet engineering:

Interference fits *		Transition fits		Clearance fits	
Shrink	Sh	Force	F	Slide	S
Heavy drive	Dh	Tight	T	Easy slide	Se
Light drive	Dl	Wringing	W	Running	R
		Push	P	Slack running	Rs
				Loose running	Rl
				Hot running	Rh

To obtain a fixed permanent joint between two parts, for instance, a wheel of a railway coach on its axle, the hole of the wheel must be heated to a temperature of 450-550°C and assembled with the cold journal of the axle. Upon cooling, the hole contracts and grips the shaft very firmly. This is an example of a *shrink fit.*

The bush in the lid of a pneumatic drill head body is also fixed, but the interference is less and assembly is carried out by press-fitting in a press in the cold state. In this case, we have a *drive fit.*

A *force fit* ensures a reliable joint between two parts, and considerable force is required to assemble them. To prevent the rotation of one part relative to the other along the joint, keys or pins are used. An example is the mounting of a coupling on the shaft of an electric motor.

---

* We have used as fit symbols the letters which correspond to the English names of the fits. It must be understood, however, that in Soviet engineering drawings, fits are specified by Russian capital letters which correspond in the same manner to the Russian names of the fits. These symbols are:

Shrink (Sh) Гр
Heavy drive (Dh) Пр
Light drive (Dl) Пл
Force (F) Г
Tight (T) Т
Wringing (W) Н
Push (P) П
Slide (S) С
Easy slide (Se) Д
Running (R) Х
Slack running (Rs) Дл
Loose running (Rl) Сл
Hot running (Rh) Тх

English names, given here to the fits of the U.S.S.R. standard, have been selected to broadly characterize their nature. It is not to be inferred that they coincide in tolerances with any fits of the same name employed in Great Britain or the United States.

A *tight fit* is used to obtain a tight joint between parts, e.g., between the inner ring of a ball bearing and the shaft. Assembly and dismantling are performed relatively seldom and with the application of considerable force. In this case, too, keys or pins may be used.

A *wringing fit* is used when assembly and dismounting of the parts must proceed without much effort, and only with the aid of a hammer. An example is the fitting of a gear on the spindle of a machine tool.

A *push fit* ensures contact between the parts, the assembly or dismantling of which must be effected by means of a mallet or by hand, as for example the fitting of the outer ring of a ball bearing in the housing bore.

In clearance fits, the clearance gradually increases from the slide fit to the hot running fit. The latter is used in joining parts subject to high temperatures in service. In such cases, different thermal expansion of shaft and hole can occur, and hence larger clearances are necessary.

Basic-hole and Basic-shaft Systems. Various fits of mating parts can be obtained by relating the hole and shaft diameters in different ways. In practice, it is advantageous to manufacture one of the parts with a constant size and to obtain the various fits by changing the size of the mating part.

A *basic-hole system* is one in which the limits of size of the hole are constant for all fits. Various fits are obtained by changing the limits of the shaft. Here, the tolerance zone of the hole remains unchanged, but that of the shaft is varied according to the fit required (Fig. 22*a*).

In the basic-hole system, the lower deviation of the hole is zero. The tolerance is equal to the upper deviation, i.e., it is always directed towards enlarging the hole.

Similarly, a system of fits in which the limits of size of the shaft are constant is known as a *basic-shaft system*. The tolerance zone of the shafts remains unchanged, whereas that of the holes varies according to the desired fit (Fig. 22*b*). The upper deviation of the shaft is zero and the lower deviation is equal to the tolerance imposed.

In mechanical engineering, the basic-hole system is normally used. This is because it is easier to manufacture

shafts of varying size than holes, since for the machining of holes, a larger number of tools (core drills, reamers, etc.) and a multitude of forms and sizes of grinding wheels are required. The manufacture of tools for use with a basic-hole system is also simpler and cheaper than for the basic-shaft system.

In certain cases, however, the application of the basic-shaft system is more advantageous. This is, for instance, the case in instrument manufacture.

The choice of a fit system is influenced by economic, process engineering and maintenance factors.

3-7. NOTATION OF TOLERANCES AND FITS

In detail drawings, it is usual to indicate the numerical values of size deviations (tolerances) either directly, or by means of a conventional letter notation of fits with a subindex showing the grade of accuracy. For second grade accuracy, which is the one most widely used, the subindex (the figure 2) is omitted.

For instance, T_1 indicates a tight fit of the first grade of accuracy; T is a tight fit of second grade accuracy; T_{2a} denotes a tight fit of the 2a grade of accuracy; S_3 indicates a slide fit of the third grade of accuracy, etc.

Holes in the basic-hole system of fits are denoted by the letter A, and shafts in the basic-shaft system, by the letter B. Thus, if a drawing of a shaft specifies the dimension, fit symbol and grade of accuracy, then the shaft is to be manufactured in the basic-hole system. If the letter B follows the shaft size, the fit of the mating parts is to be in the basic-shaft system.

Figure 23 shows how basic-hole system fits are specified in drawings. In views *a*, *b* and *c*, the size notation comprises the nominal size, conventional fit symbol and subindex of the accuracy grade, while in views *d*, *e* and *f*, the same dimensions are shown with the numerical values of tolerances in millimetres.

In assembly drawings of mating parts, it is usual to indicate the nominal size followed by the fit symbol or tolerance of the hole (in the numerator) and that of the shaft (in the denominator).

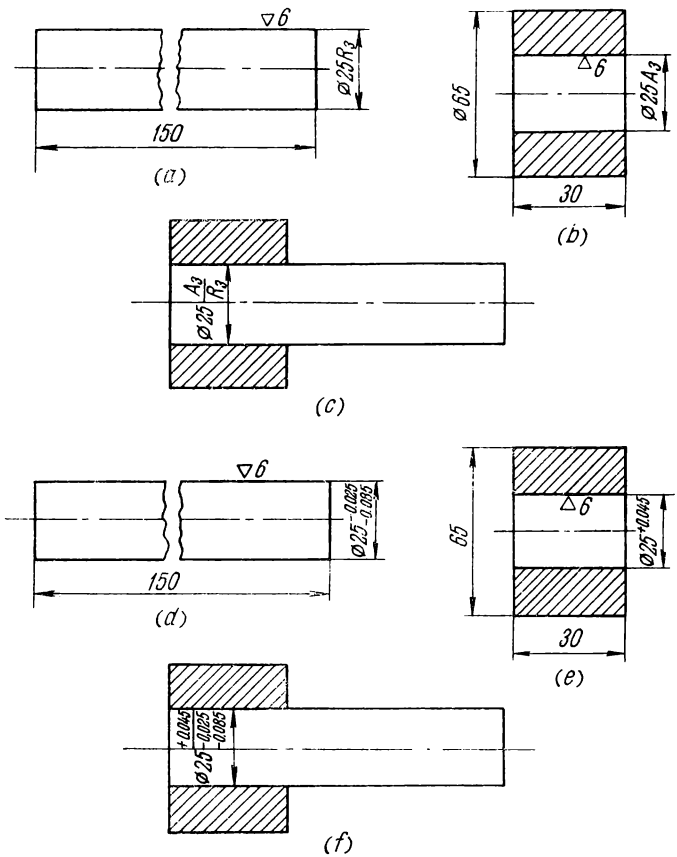


Fig. 23. Specifying tolerances in drawings:
a and *d*—shaft; *b* and *e*—hole; *c* and *f*—mating parts

3-8. GRADES OF ACCURACY

The smaller the tolerance on a part, the less will its actual size vary and the more accurate it will be. The larger the tolerance, the less accurate will the part be.

Depending on the magnitude of the tolerance, the following 10 grades of accuracy have been established in the U.S.S.R. for sizes from 1 to 500 mm: 1, 2, 2a, 3, 3a, 4, 5, 7, 8 and 9. There is no 6th grade.

Tolerances and Fits of the 2nd Grade

Dimensions in microns

Nominal diameter, mm	Hole deviations A		Fits							
			Force F		Tight T		Wringing W		Push P	
			Shaft							
	L	U	U	L	U	L	U	L	U	L
1-3	0	+10	+13	+6	+10	+4	+7	+1	+3	−3
3-6	0	+13	+16	+8	+13	+5	+9	+1	+4	−4
6-10	0	+16	+20	+10	+16	+6	+12	+2	+5	−5
10-18	0	+19	+24	+12	+19	+7	+14	+2	+6	−6
18-30	0	+23	+30	+15	+23	+8	+17	+2	+7	−7
30-40 40-50	0	+27	+35	+18	+27	+9	+20	+3	+8	−8
50-65 65-80	0	+30	+40	+20	+30	+10	+23	+3	+10	−10
80-100 100-120	0	+35	+45	+23	+35	+12	+26	+3	+12	−12
120-140 140-160 160-180	0	+40	+52	+25	+40	+13	+30	+4	+14	−14
180-220 220-260	0	+45	+60	+30	+45	+15	+35	+4	+16	−16
260-310 310-360	0	+50	+70	+35	+50	+15	+40	+4	+18	−18
360-440 440-500	0	+60	+80	+40	+60	+20	+45	+5	+20	−20

Table 2

Accuracy Basic-hole System

(1 micron = 0.001 mm)

Slide S		Easy slide Se		Running R		Slack running Rs		Loose running Rl		Hot running Rh	
deviations											
U	L	U	L	U	L	U	L	U	L	U	L
0	—6	—3	—9	—8	—18	—12	—25	—18	—35	—60	—74
0	—8	—4	—12	—10	—22	—17	—35	—25	—45	—70	—88
0	—10	—5	—15	—13	—27	—23	—45	—35	—60	—80	—102
0	—12	—6	—18	—16	—33	—30	—55	—45	—75	—98	—122
0	—14	—8	—22	—20	—40	—40	—70	—60	—95	—110	—143
0	—17	—10	—27	—25	—50	—50	—85	—75	—115	—120 —130	—159 —169
0	—20	—12	—32	—30	—60	—65	—105	—95	—145	—140 —150	—186 —196
0	—23	—15	—38	—40	—75	—80	—125	—120	—175	—170 —180	—224 —234
0	—27	—18	—45	—50	—90	—100	—155	—150	—210	—200 —210 —230	—263 —273 —299
0	—30	—22	—52	—60	—105	—120	—180	—180	—250	—260 —290	—332 —362
0	—35	—26	—60	—70	—125	—140	—220	—210	—290	—330 —360	—411 —441
0	—40	—30	—70	—80	—140	—170	—245	—250	—340	—410 —480	—507 —557

The type of process used for the machining of a hole or shaft is determined by the grade of accuracy required. To ensure 1st grade accuracy, holes are drilled, core drilled, reamed, ground and honed; shafts are rough and finish turned in a lathe, rough and finish ground, and finally lapped or superfinished.

For 2nd grade accuracy, which is standard in machine-tool engineering, tractor and automobile manufacture, electrical engineering, instrument manufacture and other fields, holes are drilled, core drilled, and rough and finish reamed or ground; shafts are rough and finish turned and then rough and finish ground.

For 3rd grade accuracy, holes are drilled, core drilled and reamed, or rough and finish reamed; for shafts, rough and finish turning in two passes is used.

In 3a grade accuracy, the parts are machined in the same way as in the ordinary 3rd grade, but with a lesser number of passes.

For 4th grade accuracy, the hole is machined by drilling through a jig at a low rate of feed or by boring in one pass; shafts are machined by turning in one pass.

In 5th grade accuracy, the holes are drilled or bored and the shafts are rough turned.

The 7th, 8th and 9th grades of accuracy correspond to cast and forged blanks, as well as to clearance (nonmating) surfaces which are rough machined.

Grinding operators are usually required to grind parts machined to an accuracy of at least the 4th grade.

Table 2 lists the tolerances for shafts and holes in the 2nd grade accuracy basic-hole system.

3-9. SURFACE FINISH

Parts can be manufactured to close tolerances only if they are machined to a high class of surface finish.

There is a difference between surface quality and surface finish. The finish of a surface is characterized by its geometrical condition, whereas the term *quality* refers not only to geometrical factors, but also to the physical state of the surface layer. The physical state of a surface implies hardness, local burns, local annealing, cracks, changes in

crystal lattice structure due to stresses arising as a result of stock removal as chips, heat generation and for other reasons.

In finishing operations, during which only thin chips are removed and in which the surface is subject to only low stresses and heat generation, the changes of physical state of the surface layer are insignificant.

The geometrical state of the surface is characterized by the degree of roughness (microirregularities) of the

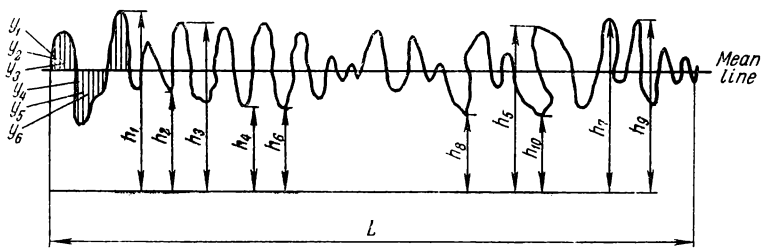


Fig. 24. Surface microirregularities

surface after machining. The height of the irregularities depends upon the shape of the cutting edge on the tool, the rate of feed, the grain size of the grinding wheel, the cutting speed, the vibration of the tool, workpiece and machine tool, etc.

The U.S.S.R. standards distinguish 14 classes of surface finish, depending on the height of the irregularities, denoted by R_z, or the arithmetical average deviation of the surface profile, R_a, in microns.

For the determination of the arithmetical average deviation of the profile (Fig. 24), all the distances from the points of the profile to the mean line are added and divided by their total number

$$R_a = \frac{y_1 + y_2 + y_3 + y_4 + y_5 + \ldots + y_n}{n}$$

The height of the irregularities R_z is determined as the mean height (peak-to-valley distance) of the five major

irregularities, measured along the length L of the base line. Thus

$$R_z = \frac{(h_1+h_3+h_5+h_7+h_9)-(h_2+h_4+h_6+h_8+h_{10})}{5}$$

In the U.S.S.R. standards, the maximum values for R_a and R_z are stipulated for each class of finish (Table 3).

Table 3

Values of R_a and R_z for Various Classes of Finish

Class of surface finish	Arithmetical average deviation of profile R_a, μ	Height of surface irregularities R_z, μ	Class of surface finish	Arithmetical average deviation of profile R_a, μ	Height of surface irregularities R_z, μ
	not exceeding			not exceeding	
1	80	320	8	0.63	3.2
2	40	160	9	0.32	1.6
3	20	80	10	0.16	0.8
4	10	40	11	0.08	0.4
5	5	20	12	0.04	0.2
6	2.5	10	13	0.02	0.1
7	1.25	6.3	14	0.01	0.05

The classes of surface finish from 6 to 14 are additionally subdivided into three categories—*a*, *b* and *c* (Table 4).

The surface finish of parts is evaluated by means of special instruments, or else by comparison with standard specimens under a microscope.

Instruments used for measuring surface finish are called profilographs, profilometers and Linnik double microscopes.

In the profilograph, the outlines of microirregularities of the surface to be measured are recorded with a magnification of ×200,000 on a paper tape, and measurements are made on the obtained profilogram.

In the profilometer, the value of R_a or R_z is indicated on the scale of the instrument, the class of finish being determined by these values.

Table 4

Arithmetical Average Deviation of the Profile and Height of Irregularities in Categories *a*, *b* and *c*

Class of surface finish	Arithmetical mean deviation of profile R_a, μ			Depth of surface irregularities R_z, μ		
	Categories					
	a	*b*	*c*	*a*	*b*	*c*
	not exceeding					
6	2.5	2.0	1.6	10	8	—
7	1.25	1.0	0.8	6.3	5.0	4.0
8	0.63	0.5	0.4	3.2	2.5	2.0
9	0.32	0.25	0.20	1.6	1.25	1.0
10	0.16	0.125	0.10	0.8	0.63	0.50
11	0.08	0.063	0.05	0.4	0.32	0.25
12	0.04	0.032	0.025	0.2	0.16	0.125
13	0.02	0.016	0.012	0.1	0.08	0.063
14	0.01	0.008	0.006	0.05	0.04	0.032

In the Linnik double microscope, a beam of light is directed at an angle onto the surface from one microscope to obtain an optical light cross section of the microprofile. This cross section is viewed through the second microscope at a large magnification. The height of the irregularities is determined from a scale in the lens, and the class of finish is then found from Table 3.

A surface finish between $\sqrt{}$ 7 and ∇ 9 can be obtained in finishing operations, i.e., grinding, broaching, reaming, precision turning and boring.

A finish between ∇ 10 and ∇ 14 can be ensured by finishing operations, i.e., high-speed precision grinding, honing, lapping and superfinishing. For some time past, a high surface finish has been attained by the application of electrochemical methods.

CHAPTER

4

Measuring inspection equipment and techniques

4-1. IMPORTANCE OF QUALITY INSPECTION IN MACHINE BUILDING

In modern production, workpieces are subjected, in the course of machining, to inspection whose aim is to check dimensions, shape, surface finish, hardness of the material and other factors.

There are many factors which impair the stability of manufacturing processes in the machining of workpieces and thereby lead to various types of rejects, i.e., workpieces which do not comply with the dimensional tolerances and other requirements specified by the drawing.

In the machining of metals, these factors include the wear of the cutting tools, deformation of the machine tool and fixture under the action of the cutting force, as a result of which the position of the cutting tool is changed relative to the workpiece, differences in size of the blanks, heating of the blanks during machining, etc.

In connection with these and many other causes, inspection in all stages of manufacturing operations and concerning all aspects of production is essential.

4-2. ACCURACY OF MEASUREMENT

Measuring involves comparing the dimension to be measured against an accepted unit of measurement.

The metre is the unit accepted in the U.S.S.R. for measuring linear lengths. The measuring system, the basis of which is the metre, is called the metric system. In some countries, measurements are made in inches.

The metre is divided into 10 decimetres; one decimetre equals 10 centimetres; one centimetre is subdivided into 10 millimetres, and one millimetre into 1,000 microns.

In the inch system, the basic unit of length is the inch, which is equal to 25.4 mm and is written as 1″.

Measurement of components is carried out with the aid of measuring devices or instruments. In each case, the instrument used should have a scale division value which is not more than one-third of the dimensional tolerances for the workpiece. Thus, in the grinding of a shaft for which the diameter tolerance is 0.03 mm, an instrument must be used with a scale division value of 0.01 mm or less, (e.g., a micrometer caliper).

Measurements must be made at the standard temperature of 20°C, at which the measuring instruments are calibrated. For accurate measurements, hot workpieces must be cooled prior to being measured.

The accuracy of measurement also depends on the pressure with which the measuring surfaces of the instrument are applied against the surface of the workpiece. Precision instruments are therefore calibrated under a definite contact pressure which is maintained automatically by the instrument itself. For example, in the micrometer, this pressure is maintained by the ratchet stop.

In practice, measuring errors can result from the faulty calibration of the instrument, its incorrect application or by disregarding the temperature requirement. The accuracy of measurement is also determined to a considerable extent by the experience and skill of the person involved.

Correct handling of the instrument is of great importance. Instruments must be protected against blows, dirt and corrosion, and must be kept in special cases lined with soft materials. Measurements must not be carried out on moving parts, since this leads to rapid wear and breakage of the instrument.

Measuring instruments must be checked periodically in service. Each instrument has a certificate in which its service period is indicated; when this period is up, the instrument must be handed in for verification.

4-3. INSTRUMENTS FOR MEASURING LINEAR DIMENSIONS

In grinding operations, an accuracy of the 2nd or 1st grade is maintained, and therefore the instruments used for measuring ground work are of high precision.

Measuring instruments are classified under two groups:
(1) universal instruments determining the actual size (vernier calipers, micrometer calipers, etc.); and
(2) instruments which check the limits of any one size (gauges, templets).

Vernier Calipers. These are universal measuring instruments (tools) designed for measuring diameters, lengths and other linear dimensions.

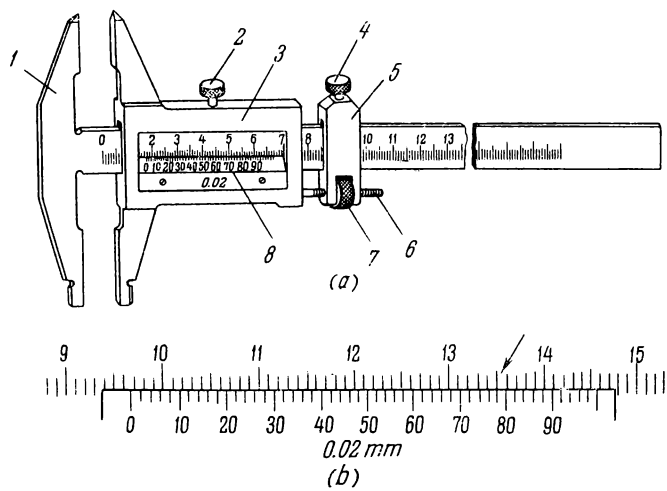


Fig. 25. Vernier caliper reading to 0.02 mm:
a—general view; *b*—vernier scale

In the U.S.S.R., vernier calipers are available with measuring ranges of 125, 150, 200, 300, 500, 800, 1,000, 1,500 and 2,000 mm with an accuracy of 0.1, 0.05 and 0.02 mm.

Figure 25*a* shows a vernier caliper reading to 0.02 mm. The fixed jaws are integral with steel beam *1*, on which a scale, graduated in millimetres, is engraved. Head *3* slides along beam *1*. The head carries integral sliding jaws and vernier scale *8*. The latter has 50 divisions, whose total length is 49 mm (Fig. 25*b*). Thus, one division on the vernier scale corresponds to $\frac{49}{50} = 0.98$ mm. Hence, one division on the vernier scale is smaller than a division on the beam scale

by 1 — 0.98 = 0.02 mm. This difference in size between the division on the strip and on the vernier scales enables readings to be made with an accuracy of 0.02 mm. The size, in hundredths of one millimetre, is indicated by that vernier scale line which coincides with a line on the beam scale.

In Fig. 25*b*, the vernier scale line corresponding to 0.78 mm is indicated by an arrow.

The whole number of millimetres in the measured dimension is indicated by the nearest line of the beam scale to the left of the zero line of the vernier scale. In the above example, this is 96 mm. Thus, the measured size is 96.78 mm.

Also mounted on beam *1* is auxiliary slide *5* with the fine adjustment screw *6*. The slide is clamped on the beam by thumb screw *4*. On revolving nut *7* of the slide, screw *6*, which is attached to head *3*, moves forward, and a definite gripping pressure is produced between the jaws. In the final position, head *3* is clamped on the beam by thumb screw *2*.

Prior to taking readings, it is necessary to check whether the vernier caliper is in working order. The measuring surfaces of the jaws must be clean, free from warping and dents. The jaws are closed and checked for clearances by light passing through. In this position, the zero lines of the vernier and the beam scale of accurate calipers should coincide.

The head and auxiliary slide must move smoothly along the beam. The pressure exerted by the thumb screws of the head and slide must not distort the jaws or shift them from the set size.

During measurement, the caliper jaws must not be cocked relative to the work, or else incorrect readings will be obtained (Fig. 26).

In measuring small parts, the latter are held in the left hand and the vernier caliper in the right. The sliding jaw is pressed lightly against the component with the thumb of the right hand. After clamping the slide,the nut is turned with the thumb and index finger of the right hand.

Bulky workpieces are placed on a table and measured in this position. For the measurement, between machining operations, of a shaft mounted between the centres of a ma-

chine tool, the stationary jaw is supported with the left hand, while the right hand moves up the sliding head, clamps the slide thumb screw, turns the nut of the fine adjustment screw and finally clamps the head with its thumb screw. The caliper is then removed and the reading taken.

The width over the external measuring faces of the jaws is marked on one side (see Fig. 25). These faces are used for measuring hole diameters after inserting them into the bore. To the vernier reading is added the width of the jaws, the total representing the size of the hole diameter.

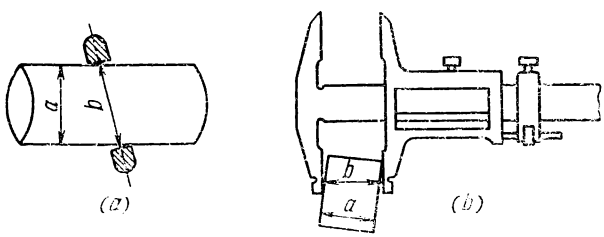


Fig. 26. Incorrect position of the vernier caliper in measuring:
a—diameter; *b*—width

Examples of measurements carried out with vernier calipers are shown in Fig. 27.

Vernier depth gauges (Fig. 28) are built on the same principle as the vernier caliper and are designed for the measurement of depths and heights. They consist of beam *3*, sliding head *4*, with base *1* and vernier scale *5* attached to it. Beam *3* moves within head *4*.

The measuring surfaces of the vernier depth gauge are the lower surface of base *1*, and the end face *2* of beam *3*. When the zero lines of the vernier and beam scales coincide, the measuring surfaces of the base and beam lie in one plane (flush with each other).

The vernier depth gauge is read in the same way as the vernier caliper.

The upper limits of measurement of vernier depth gauges are 100, 125, 150, 250, 300 and 400 mm. The vernier scales can be read to 0.1, 0.05 or 0.02 mm.

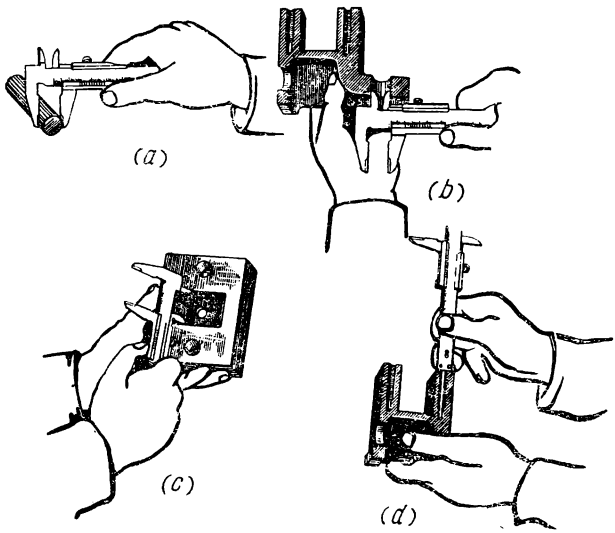


Fig. 27. Using a vernier caliper to measure:
a—shaft diameter; *b*—hole diameter; *c*—groove width; *d*—hole depth

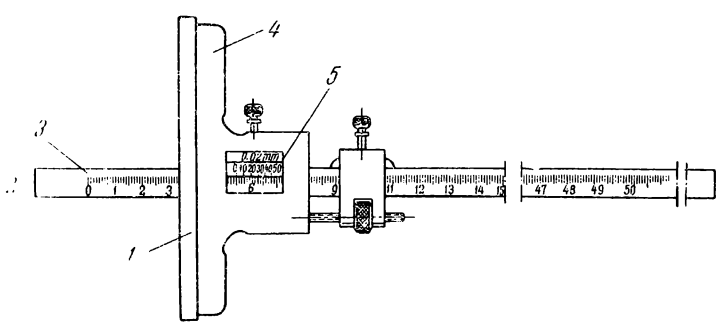


Fig. 28. Vernier depth gauge

The Micrometer Caliper. Micrometer calipers, or simply micrometers, are used for measuring lengths, thicknesses and external diameters of workpieces with an accuracy up to 0.01 mm. Measurements up to 1,600 mm can be made with a micrometer.

The micrometer screw can travel only 25 mm, and therefore micrometers are made with ranges of measurement from 0 to 25 mm, or 25 to 50 mm, or 50 to 75 mm, etc. A micrometer set includes a standard of a size equal to the lower measuring limit of the instrument. The standard is used for setting and testing the micrometer.

A longitudinal sectional view of a micrometer is shown in Fig. 29*a*.

Heavy frame *1* of the micrometer carries the fixed anvil *2*, with its measuring face, on one side, and press-fitted barrel *5* on the other. The right-hand end of the barrel is spindle nut *14* with precision internal thread having a pitch of 0.5 mm. Rotation of measuring screw *7* in this thread results in precise axial travel of the screw, one complete revolution of the screw corresponding to a travel of exactly 0.5 mm. The second measuring face is the end of spindle *3* which is integral with screw *7*.

Spindle nut *14*, at the end of barrel *5*, has equally spaced longitudinal slits cut around its circumference, similar to those of a spring collet, and tapered external thread *13*. With the aid of adjusting nut *9*, screwed on the tapered thread, excess clearance, due to wear, can be eliminated in the thread of nut *14* and measuring screw *7*.

A linear scale with 0.5 mm divisions is engraved on sleeve *6* which is press-fitted on the barrel.

Thimble *8* is secured on tapered end *11* of measuring screw *7* by means of thimble cap *10*. The thimble rotates and moves axially along barrel sleeve *6* when the measuring screw is rotated. A circular scale with 50 divisions is engraved on the bevelled edge of the thimble. Readings of hundredths of a millimetre are read off on this scale.

Rotation of the thimble through one division corresponds to 1/50 of a revolution of measuring screw *7*. Since its pitch is 0.5 mm, 1/50 of a revolution corresponds to an axial travel of 1/50 0.5 mm = 0.01 mm which is the value of the scale divisions on the thimble scale.

To maintain a definite measuring pressure, ratchet stop *12* is provided. It is turned with the thumb and index finger and transmits rotation to screw *7* until the pressure of the

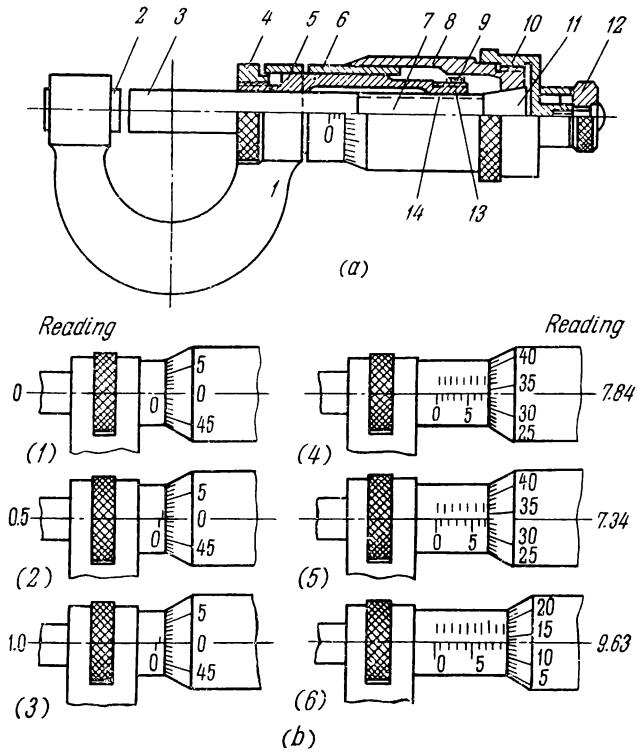


Fig. 29. Micrometer caliper:
a—construction; *b*—taking readings

spindle in contact with the work being measured exceeds the required value, after which the ratchet stop begins to slip and clicks will be heard.

Clamp ring *4* locks the micrometer spindle at a definite setting.

Reading the micrometer. Whole and half-millimetres are read off on the scale of barrel sleeve *6*. The bevelled edge of thimble *8* indicates the size on this scale.

First of all, the number of lower divisions of the longitudinal scale is determined. Each is equal to 1 mm. The upper lines of the scale divide the lower millimetre intervals into two halves, i.e., if an upper line is visible to the right of the last lower line, then 0.5 mm must be added to the whole number of millimetres obtained. Further, it is ascertained which line of the circular scale on the thimble coincides with the longitudinal line of the barrel sleeve scale. The figure obtained is the number of hundredths of a millimetre, and must be added to the value obtained earlier.

Six examples of micrometer readings are shown in Fig. 29*b*.

	mm
(1) No whole millimetre division is seen below the longitudinal line	0
No line above the longitudinal line is visible to the right of the lower extreme right-hand line of the scale	0.0
The zero division line on the thimble coincides with the longitudinal line on the barrel sleeve	0.00
Reading	0
(2) No whole millimetre division is seen under the longitudinal line	0
One line above the longitudinal line can be seen to the right of the lower extreme right-hand scale line	0.5
The zero division line on the thimble coincides with the longitudinal line on the barrel sleeve	0.00
Reading	0.5
(3) One whole millimetre division is seen under the longitudinal line	1.0
No line above the longitudinal line is visible to the right of the lower extreme right-hand scale line	0.0
The zero division line on the thimble coincides with the longitudinal line on the barrel sleeve	0.00
Reading	1.0
(4) Seven whole millimetre divisions are seen under the longitudinal line	7.0
A line above the longitudinal line can be seen to the right of the lower extreme right-hand scale line	0.5

	mm
The line of the 34th division on the thimble coincides with the longitudinal line on the barrel sleeve	0.34
Reading	7.84

(5)

Seven whole millimetre divisions are seen below the longitudinal line	7.0
No line above the longitudinal line can be seen to the right of the lower extreme right-hand scale line	0.0
The line of the 34th division on the thimble coincides with the longitudinal line on the barrel sleeve	0.34
Reading	7.34

(6)

Nine whole millimetre divisions are seen below the longitudinal line	9.0
A line above the longitudinal line can be seen to the right of the lower extreme right-hand scale line	0.5
The line of the 13th division on the thimble coincides with the longitudinal line on the barrel sleeve	0.13
Reading	9.63

Figure 30 shows how measurements are made with a micrometer.

The micrometer depth gauge and inside micrometer, also reading to 0.01 mm, are similar to the micrometer caliper both in construction and working principle.

The micrometer depth gauge (Fig. 31) is used for measuring depths of holes and heights of shoulders. Base *1* is held against the work, and by turning thimble *2* with the aid of ratchet stop *3*, spindle *6* is advanced to the bottom of the hole or slot being measured. The dimension obtained is read off the scales on thimble *2* and barrel *4*. The latter is fixed to base *1* by locking device *5*.

The inside micrometer (Fig. 32) is used for measuring internal dimensions. It consists of micrometer head *2* and anvil *1*. The micrometer head, like that of a micrometer caliper, consists of a barrel, measuring screw, located inside the barrel, with a measuring face on an anvil passing through the thimble cap, a thimble with divisions, thimble cap and a locking device,

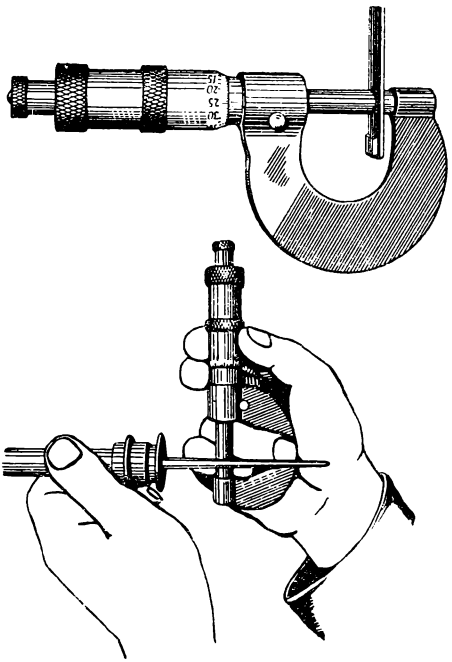


Fig. 30. Using the micrometer

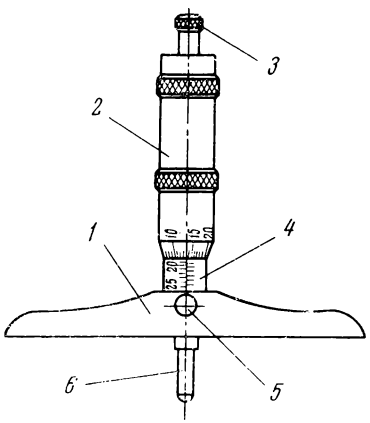
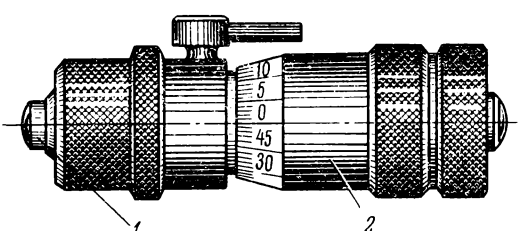
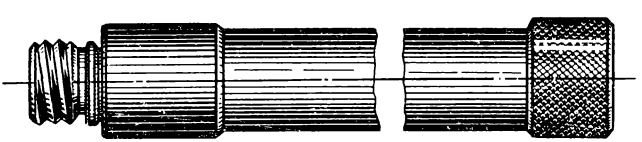


Fig. 31. Micrometer depth gauge



(a)



(b)

Fig. 32. Inside micrometer:
a—head; b—extension

Heads of inside micrometers are available with two lower limits of measurement: 75 and 150 mm.

To measure larger sizes, extensions are attached to the heads. This enables sizes up to 4,000 mm to be measured. In such cases, the size of the extension is added to the reading of the micrometer head.

A number of rules must be observed in connection with the use of micrometers and other micrometric instruments:

1. Measurements should be carried out at a temperature of 20°C.

2. Prior to carrying out measurements, the condition and reading of the micrometer must be checked (it must be free from dents and damage). For this purpose, in the case of a micrometer with a measuring limit of 0, the two measuring faces are brought into intimate contact by means of the ratchet stop. In this position, the micrometer reading should be 0. Micrometers of larger sizes are checked and adjusted by means of standards.

3. Work must be measured without cocking the micrometer.

4-4. INSTRUMENTS FOR CHECKING AND MEASURING ANGLES

Angles are measured by means of angle block gauges, templets, squares, universal protractors and other instruments.

Angle block gauges are used separately or in combinations for checking angles. They are available either of triangular shape with one working angle, or of quadrangular shape with four working angles. Sets of 19, 36 and 94 blocks, as well as sets of five blocks having angles of 15°, 30°, 45° and 60°, are available.

Angle block gauges of the 1st and 2nd classes of accuracy have angles accurate to within $\pm$ 10″ and $\pm$ 30″, respectively. The error involved in measuring angles, using a block gauge and observing the light passing through when the gauge is applied to the work, depends on the surface finish of the workpiece, the length of the sides making the angle and the intensity of illumination. The error is within the sum of the tolerance on the angle of the gauge plus 15″.

Sets of angle block gauges also include holders, wedge pins and screws for making up gauge combinations. Fig. 33 shows the method of measuring angles with a combination of angle block gauges.

Protractors are used for measuring angles by the contact method, reading off the angle on a vernier scale.

Two general types of protractors are available. The first type (Fig. 34*a*) is used for measuring external angles

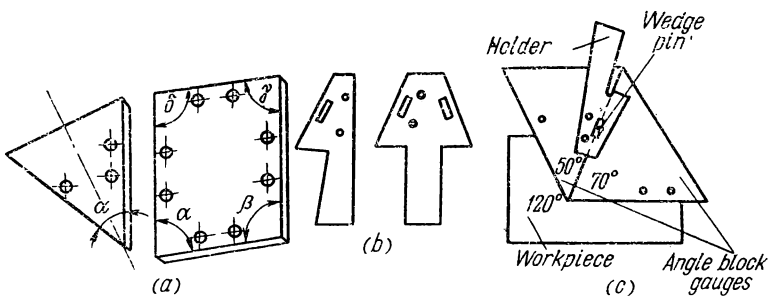


Fig. 33. Measuring angles with angle block gauges:
a—angle block gauges; *b*—holders; *c*—checking an angle

between base *1* and blade *7* which can be rotated about joint *6*. The base and blade have scales *2* and *4* on which the readings are made. The protractor reads to 2′.

Proper contact between the base and blade and the sides of the angle is achieved by means of micrometric screw *3*. For measuring angles between 0 and 90°, acute angle attachment *8* is attached to the blade. After setting the protractor to the required angle, the blade is fixed in position with thumb nut *5*.

Both external and internal angles of workpieces and templets can be measured with the second type of protractor, designed by D. Semyonov (Fig. 34*b*). Segment *4*, to which vernier *8* is attached, moves along base segment *1*, on which the main scale with 1° divisions is engraved. Square *5* is attached to this segment by means of holder *7*. Blade *6* is attached to the square. Straight edge *2* is firmly attached to base *1*. The protractor is also provided with locking

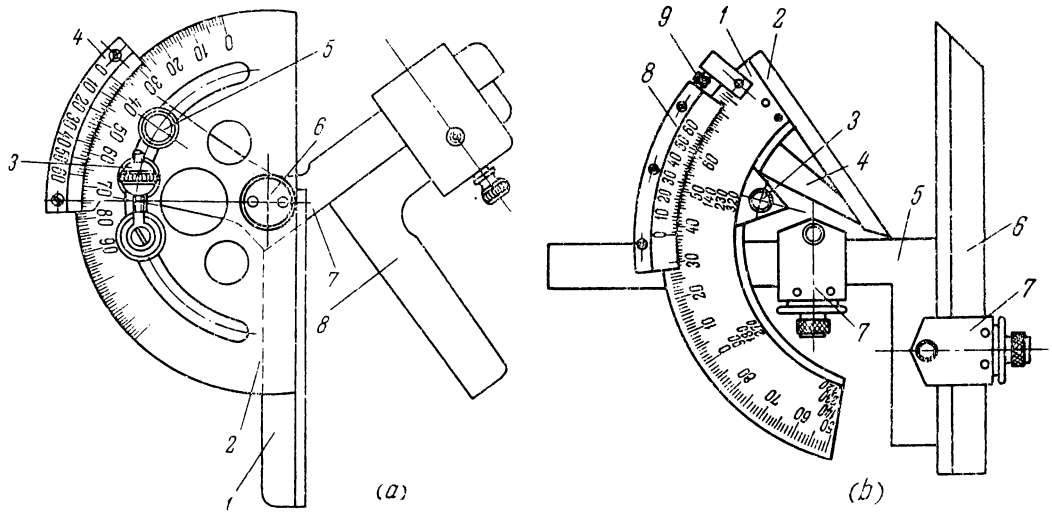


Fig. 34. Universal protractors:
a—protractor for measuring external angles; *b*—protractor designed by D. Semyonov

device *3* and micrometric screw *9*. By means of this protractor, angles within a range of 0 to 320° can be measured. The vernier scale reads to 2′.

4-5. INSPECTION OF THREADS

Threads can be checked by means of screw pitch gauges, screw pitch comparators, screw-thread micrometer cali-

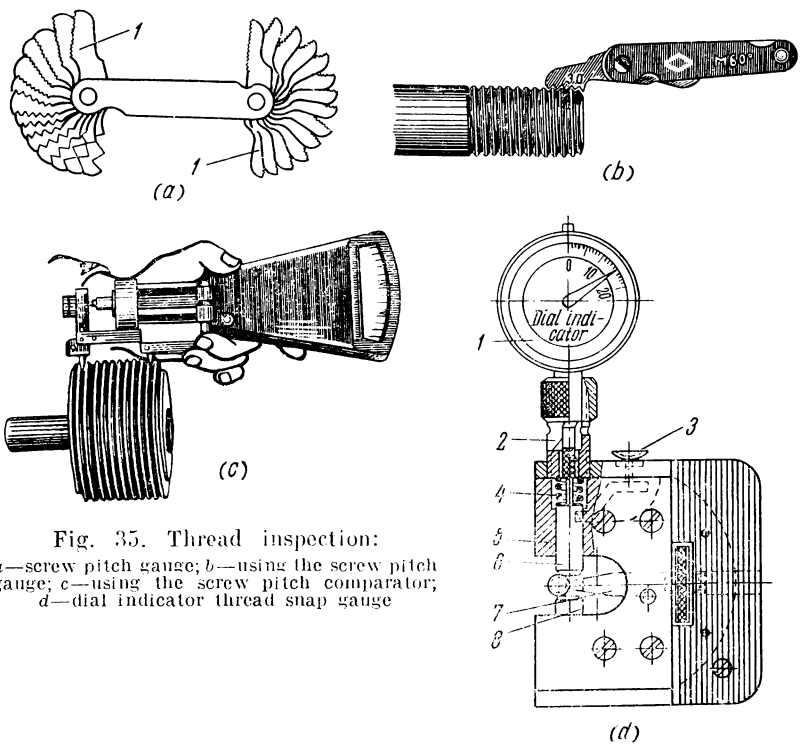


Fig. 35. Thread inspection:
a—screw pitch gauge; *b*—using the screw pitch gauge; *c*—using the screw pitch comparator; *d*—dial indicator thread snap gauge

pers, dial indicator thread snap gauges, plug thread gauges, by the three-wire method, in toolmaker's microscopes, etc.

Screw pitch gauges (Fig. 35*a*) are used to determine the pitch of external threads. They consist of flat steel blades *1* assembled in a set, notched with the profiles of metric or English threads and of various pitches in accordance with

the standards. The pitch of a thread is determined by applying the blades to the thread until the proper blade tightly fits the thread profile.

Screw pitch comparators (Fig. 35*c*) are used for comparative measurements of the thread pitch. They are provided with two ball-shaped contacts which are applied to the threaded workpiece. One contact is fixed to the body of the instrument and the other is linked to the spindle of a dial comparator through a system of levers. It is applied to a reference standard and the movable contact is set to zero. When subsequently applied to the thread to be measured, the instrument will show the deviation of the pitch from that of the reference standard.

Dial indicator thread snap gauges (Fig. 35*d*) are designed for the comparative measurement of the thread pitch diameter. In body *5* of the gauge are mounted the sensitive and fixed thread anvils *6* and *8*. Anvil *6* contacts the spindle of dial indicator *1* held in sleeve *2*. Spring *4* advances the sensitive anvil to the thread being checked. For rapid location on the thread, backstop *7* is used. Detent *3* retracts sensitive anvil *6* before applying the gauge to the thread.

In lot and mass production, threads are inspected by means of thread gauges, made in the form of Go and Not-go ring thread gauges (for checking external thread) and of plug thread gauges (for inspecting internal thread).

4-6. LEVER-TYPE MEASURING INSTRUMENTS

Mechanical lever-type instruments enable measurements to be taken with greater accuracy than those taken with vernier calipers and micrometers.

The accuracy of measurement with these instruments can attain 0.001 mm and is achieved by means of additional lever systems transmitting motion from the contact point to the scale hand of the instrument.

The range of measurement of these instruments is small and hence they are used mainly for comparative measurements. Dial comparators, dial indicators, passmeters and other devices are all lever-type instruments.

Dial Comparators. This is a measuring device having a lever transmission and designed for measuring precision parts.

The construction of a mechanical dial comparator is shown in Fig. 36*a*. Spindle *1* is linked to V-block *3* through rocking knife-edge *2*.

V-block *3* is supported by fixed knife-edge *4*. Attached to V-block *3* is hand *5*. One end of spring *6* is attached to V-block *3* and the other to the body of the instrument.

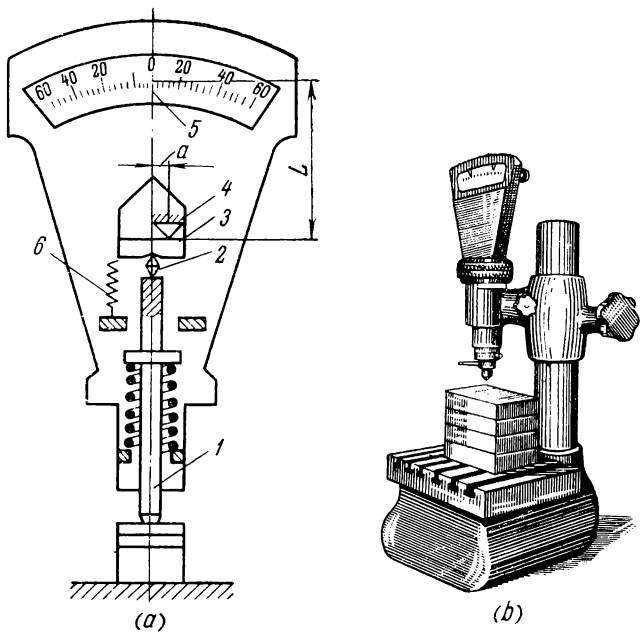


Fig. 36. Mechanical dial comparator:
a—principle; *b*—mounted on a stand with a table

The action of the spring ensures constant contact between knife-edge *2* and the V-block, and produces the measuring pressure. As the spindle is moved upwards or downwards, the V-block is swivelled and the hand attached to it swings to the right or to the left.

The distance between the rocking fixed knife-edges represents the small arm *a* of the lever, and the distance from the fixed knife-edge to the end of the hand, the large arm *L*.

The ratio of hand movement to spindle movement, called the amplification of the instrument, is equal to $\frac{L}{a}$.

In the commonly used dial comparators, the small arm a is equal to 1.0, 0.5, 0.2 or 0.1 mm, and the large arm L equals 100 mm. For these sizes, respectively, the amplification of the instrument will be 100, 200, 500 or 1,000.

The scale of a dial comparator has 1 mm divisions and, depending on the ratio between the arms, the value of one division may be 0.01, 0.005, 0.002 or 0.001 mm.

For taking measurements, the dial comparator is attached to a stand with a table (Fig. 36*b*). The comparator is set to a definite size as follows. The contact point is attached to the spindle, the table is wiped with a clean rag, and a combination of gauge blocks is placed on it. The combination is selected so that its size is equal to the nominal size of the articles to be measured.

The hand of the instrument is then set to the zero position when the contact point rests on the gauge blocks. Then the gauge blocks are removed and the article is placed on the table. The deviation of the size of the article is equal to the maximum deflection of the hand from the zero position.

The Dial Indicator. Dial indicators are widely used for engineering measurements. Dimensional errors of workpieces, runout of work being set up in a machine tool for machining, etc., are determined by dial indicators.

These are measuring devices with gear transmissions from the spindle to the indicating hand. The hand revolves on a staff (shaft) enabling readings to be made on a circular scale having divisions corresponding to 0.01 mm of spindle movement.

The range of measurement may be from 0 to 10 mm or 0 to 5 mm, for the standard type of dial indicator, and from 0 to 5, or 0 to 2 mm, for small-size dial indicators.

The construction and principle of operation of dial indicators are shown in Fig. 37. Contact point *8* is fixed in spindle *7*. The latter travels within stem *6*. The middle part of the spindle is a gear rack, which meshes with pinion *1*. Pinion *14* and large gear *10* are mounted on the same staff. Gear *10* meshes with gear *11* on the staff of which large

hand *5* is also mounted. Hand *5* indicates hundredths of a millimetre on scale *2*.

Small hand *4*, rigidly mounted on the staff of pinion *14*, indicates the number of revolutions of hand *5*, i.e., the number of whole millimetres of spindle movement. The

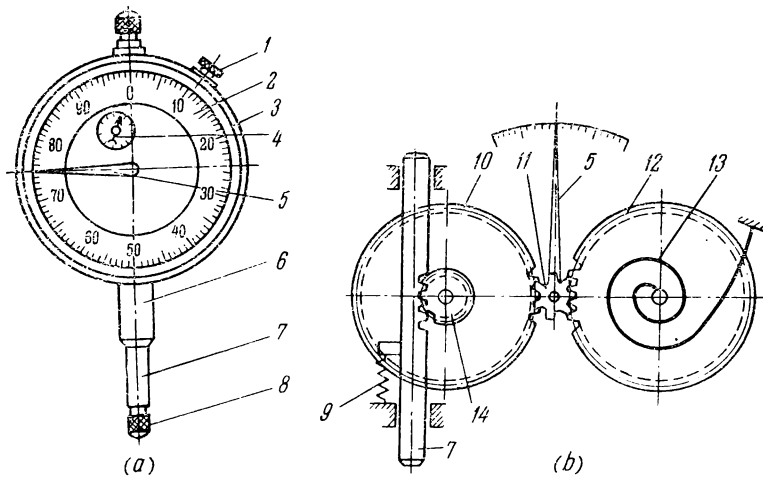


Fig. 37. Dial indicator:
a—general view; *b*—principle

force exerted by spiral hair spring *13*, acting on gear *12*, which meshes with gear *11*, eliminates the backlash in the gearing. Spring *9* exerts a definite constant pressure on spindle *7*.

The main circular scale is accommodated on revolving bezel *3* and can be set in any position. Locking screw *1* fixes the scale in this position.

At present, dial indicators reading to 0.002 mm are available. This accuracy is achieved by the provision of an additional pair of gears in the mechanism.

Dial indicators are attached to test sets (Fig. 38) or to the holders of measuring tables similar to the arrangement of dial comparators.

A dial-type adjustable snap gauge, or passmeter (Fig. 39) is used for measuring external surfaces with an accuracy up to 0.002 mm.

All the components of the gauge are accommodated within body *13*. Adjustable anvil *9* is rigidly fixed by means of clamping screw *14*.

Movable spindle *1* is retracted by pressing detent button *3*, acting through lever *2*, in order not to damage it when the gauge is applied to the workpiece being checked. When anvil *9* contacts the workpiece, detent button *3* is released

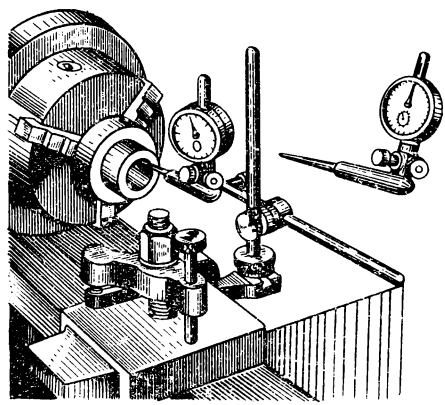


Fig. 38. Dial indicator mounted on a test set

and spindle *1* is advanced by a spring until it comes into contact with the surface of the workpiece with a definite pressure (1 kg). At the same time, lever *8* is turned through a certain angle and segment gear *7* at its end transmits rotation to pinion *6* with which it meshes. Mounted on the staff of pinion *6* is hand *5*, which moves along scale *4* and indicates the actual size of the workpiece. Tolerance hands *11* can be set to the limits of size.

A highly accurate reading is obtained because even the least movement of spindle *1* causes a considerable displacement of lever *8*, and hence also of hand *5*.

To set the instrument to a definite size, a standard is used (a combination of gauge blocks or a master). For this purpose, clamping screw *14* is released and by turning the setting screw *10*, adjustable anvil *9* is withdrawn to the right. The standard is then applied and the adjustable anvil

is advanced to the left by means of the setting screw, till it acts, through the standard, on movable spindle *1* and

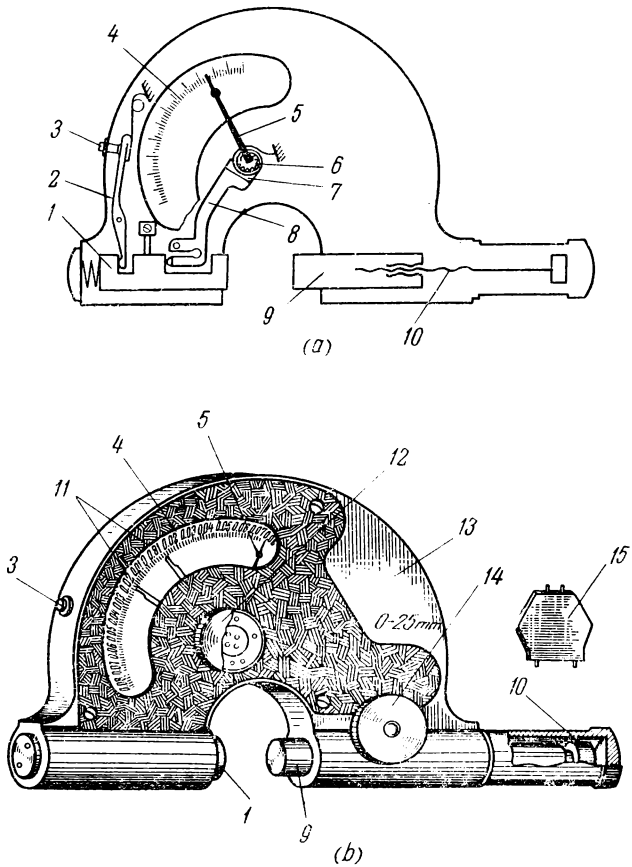


Fig. 39. Dial-type adjustable snap gauge:
a—principle; *b*—general view

on hand *5*. When the hand reaches the zero division, the adjustable anvil is fixed by means of the clamping screw. The movable spindle is then withdrawn by pressing detent button *3*, and the standard is removed.

The zero setting is verified two or three times. Cap *12* is then removed, and by means of wrench *15* and a device for regulating (setting) the red tolerance hands *11*, the tolerance zone for the required size is set up. The cap is then replaced and the gauge is ready for use. If in measuring, hand *5* takes up a position between the two hands *11*, then the part has been manufactured within the limits of the tolerance zone. By means of these gauges, not only the

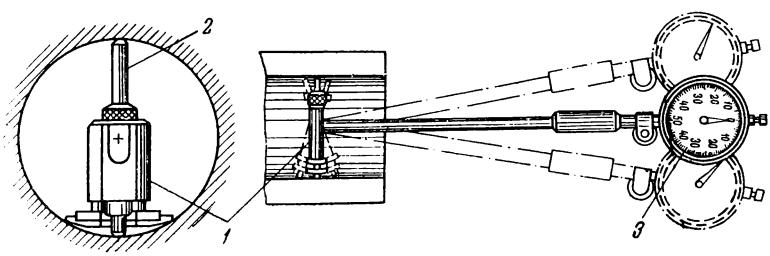


Fig. 40. Measuring an internal diameter with an inside dial gauge

actual size of a shaft, but also the magnitude of such errors as out-of-roundness and taper can be determined. Dial-type snap gauges exclude inspection errors which are inherent in the use of rigid snap gauges due to their distortion when applied to the workpiece.

Inside Dial Gauge. This instrument (Fig. 40) is used for inspecting hole diameters. It consists of gauging head *1* and dial indicator *3*.

The dimension detected by the gauging head is transmitted to the indicator by a lever system.

Prior to taking measurements, the gauge is set by means of a micrometer or setting ring to a definite size (the indicator hand being set to zero). On introducing the gauging head into the hole to be measured, the dial indicator will show the deviation from the specified dimension (deviation of the indicator hand from the zero position).

To extend the range of measurement by such gauges, they are provided with interchangeable fixed contacts *2* of different length.

4-7. LIMIT GAUGES

Under lot and mass production conditions, when identical components are manufactured in very large quantities, the measurement of these components by universal measuring tools (micrometers, vernier calipers, etc.) is inconvenient, since a lot of time is expended and considerable patience and skill are required of the worker. Under such conditions, rigid measuring tools, known as *limit gauges*, are mainly used.

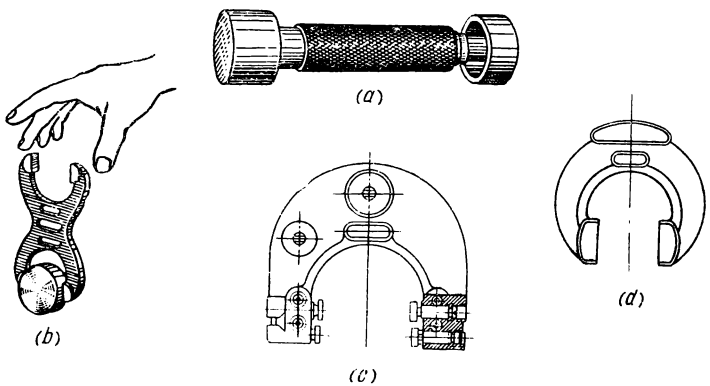


Fig. 41. Limit gauges:
a—double-ended plug gauge; *b*—double-ended snap gauge; *c*—adjustable-type snap gauge; *d*—plain solid snap gauge

Gauges for the inspection of shafts are called *snap gauges* and those for checking holes, *plug gauges*.

The sizes of limit gauges used in a particular case correspond to the maximum and minimum limits of size of the given part. The operation of measuring is then reduced to comparing the dimensions of the part with these limits.

In snap gauges, the Go size corresponds to the maximum limit of size of the part, the Not-go size, to the minimum limit of size.

In plug gauges, the Go size corresponds to the minimum limit of size of the part, and the Not-go size, to the maximum.

Limit gauges (Fig. 41) are made in the form of double-ended plug gauges, double-ended snap gauges, adjustable-type snap gauges and plain (nonadjustable) snap gauges

Adjustable snap gauges are available for dimensions up to 500 mm, and the size is adjustable within a small range.

For the measurement of a shaft with a double-ended snap gauge the Go side of the gauge must pass over the shaft under its own weight, while the Not-go side must not. The Go and Not-go sides are correspondingly marked.

To speed up inspection, single-ended limit snap gauges are used. The front pair of anvils are the Go, and the reto pair, the Not-go feature of the gauge. If the work fails ar pass through a Go gauge (or Go set of anvils), then its diameter is too large. Such a reject can be reclaimed by further machining.

When work passes through both the Go and Not-go gauges, it must be completely rejected, since it is undersized, and therefore unsalvable. Consequently, one aim in production is to keep the sizes nearer to the upper limit.

4-8. GAUGE BLOCKS

Gauge blocks are measuring instruments of high precision. These gauges can be used to measure the linear dimensions of tools and parts manufactured to a high degree of accuracy, and to set measuring tools, instruments and other devices to the zero position for comparative measuring methods (comparators, etc.). They may also be used to verify the accuracy and calibration of measuring tools and instruments, to adjust machine tools, etc.

Gauge blocks are hardened, ground and lapped steel blocks, having the shape of rectangular parallelepipeds, with very precisely machined measuring surfaces. Blocks up to 10 mm in size have a rectangular cross section 9×30 mm, and blocks larger than 10 mm, 9×35 mm.

Gauge blocks are supplied in sets. The most widely used set consists of 83 blocks of the following sizes:

1.005 mm	1 pc
1.01, 1.02, 1.03, 1.04, etc., up to 1.49 mm	49 pcs
0.5, 1, 1.5, 2, 2.5, etc., up to 10 mm	20 pcs
1.6, 1.7, 1.8, 1.9 mm	4 pcs
20, 30, 40, 50, etc., up to 100 mm	9 pcs

So-called micron sets are also used. These consist of the following 9 blocks: 1.001, 1.002, 1.003, 1.004, 1.005, 1.006, 1.007, 1.008 and 1.009 mm.

The nominal size is etched on each block.

To obtain the required size, the blocks are selected and assembled into a stack. The number of blocks in one stack, or combination, should be kept as small as possible.

A stack of a given size is made up by combining the required block of the micron series in the set with others of the one-hundredth and one-tenth series, ending finally with one or more blocks a whole number of mm in length (millimetre series). In this way, sizes with an accuracy up to 0.001 mm can be obtained.

4-9. OPTICAL, PNEUMATIC AND ELECTRICAL MEASURING DEVICES

Optical, pneumatic and electrical devices are widely used in up-to-date measuring instruments. They enable a high accuracy and efficiency to be attained in measurements, and it is also possible to use them for mechanized and automated controls.

Optical Devices. Among the optical devices, projectors, microscopes and lever-type optical measuring instruments (optical comparators enabling readings to be made off a scale having 0.001 mm divisions) are in common use.

Pneumatic instruments are based on the laws governing the escape of gases from a nozzle. Air passes under constant pressure P_1 (Fig. 42) into chamber A through an aperture F_1, and from there it escapes to the atmosphere through an aperture of cross section F_2. The air pressure P_2 in chamber A will depend on the cross section of the apertures F_1 and F_2, and the distance l from the aperture F_2 to the plane B.

At constant cross sections F_1 and F_2, the pressure P_2 in the chamber will depend on the value of l. Thus, from the value of P_2, the value of l can be obtained. The closer plane B is to aperture F_2, the higher P_2 will be; and the further away plane B is, the lower the pressure P_2 will be in the chamber.

Pneumatic instruments (air gauges) are used in conjunction with water manometers or with float-type indicating devices, which measure the air pressure P_2.

Electrical gauging instruments consist of various types of dimensional contact, induction, capacity, photoelectric and other transmitters, or pickups, in conjunction with various devices and scales.

Their working principle consists in sliding the workpiece to be measured under a sensitive spindle. Depending on the size, the spindle is displaced a certain distance, and closes the electrical contacts of a transmitter or changes

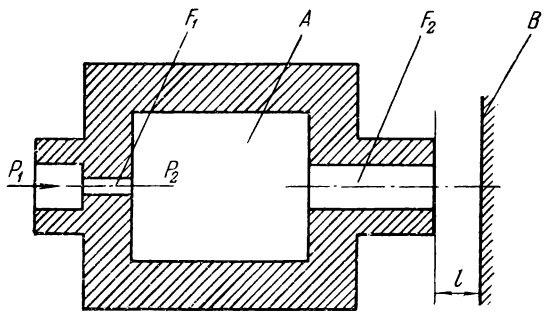


Fig. 42. Principle of the pneumatic gauge

the coefficient of self-induction in induction pickups, the capacitance in capacity pickups, and the magnitude of the photoelectric effect in photoelectric transducers. Pickups are calibrated against master or reference workpieces. The principles of operation of various pickups are shown in Fig. 43.

The *electric-contact transmitter* (Fig. 43*a*) sends a signal, i.e., it sets up a voltage in the circuit when one of the contacts, *6* or *7*, closes. If the size of a part is larger than the upper limit, contact *6* will close, and if it is less than the lower limit, contact *7* will close. When the dimensions of a component are within the tolerance limits, the contacts will remain open.

The action of an *induction pickup* (Fig. 43*b*) is based on the fact that when workpiece *5* passes under contact point *4*, sensitive spindle *3* is displaced, thereby shifting armature *1*. The gap increases between the armature and the core of one coil, and decreases between it and the other coil, as a result

of which the inductance of the first coil decreases and that of the second increases. The pickup is set up to the limits of size of a workpiece, so that it feeds signals if the size of the workpiece exceeds the limiting values.

In the photoelectric transducer (Fig. 43*c*), spindle *1* gradually closes slit *5* when the sizes of the workpieces gradually change, and will affect the amount of light falling on photoelectric cell *6* from source *4*. This alters the electric

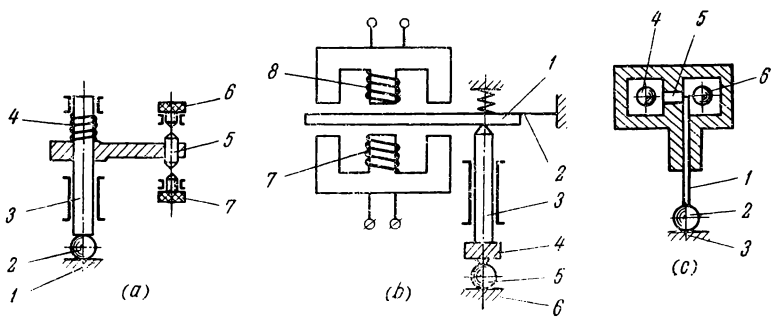


Fig. 43. Principle of operation of various transmitting elements:
a—electric-contact transmitter: *1*—flat surface; *2*—workpiece; *3*—sensitive spindle; *4*—spring; *5*—contact bridge; *6* and *7*—fixed contacts; *b*—electric induction pickup: *1*—armature; *2*—flat spring; *3*—sensitive spindle; *4*—contact point; *5*—workpiece; *6*—flat surface; *7* and *8*—coil cores; *c*—photoelectric transducer: *1*—sensitive spindle; *2*—workpiece; *3*—flat surface; *4*—source of light; *5*—light slit; *6*—photocell

current passing through the photoelectric cell, and when the size of the workpiece is no longer within the permissible limits, the transducer will send the appropriate signal.

The most important property of the pickups is that they can be combined with other devices capable of sorting components according to their sizes, without the participation of workers. They can also switch off machines or change their operation when the workpieces have attained the required size.

4-10. AUTOMATIC GAUGING IN GRINDING

Automatic gauging enables measurements of the work to be carried out without direct participation of the worker. The production of workpieces of the required size is assured

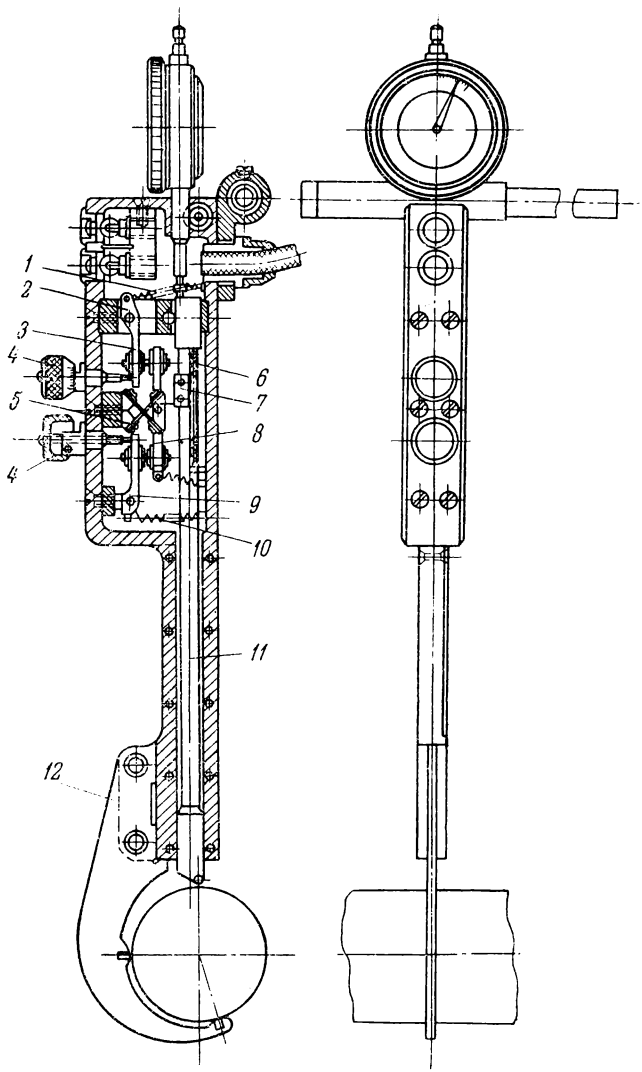


Fig. 44. Caliper-type automatic gauging device

and the worker is freed to operate other machines in the time made available.

Sizing devices are widely used in grinding machines. In particular, caliper-type gauging devices of various constructions, and size pickups are used for automating dimensional inspection in grinding shafts. Figure *44* illustrates an automatic caliper-type gauging device.

Gauge member *12*, fixed with the whole device to a bracket on the grinding wheel guard, is applied to the work being ground. By means of a special buffer, the member and its fixed contacts are held tightly at all times against the workpiece being ground. These contacts are faced with cemented carbide in order to reduce their wear. As the diameter of the workpiece decreases during grinding, sensitive spindle *11* moves downwards under the action of spring *6*. Through angle-piece *7* it then actuates contact lever *8*, which is fixed to the body by means of a flat, cross-shaped spring *5*. When lever *8* closes fixed contacts *3* mounted on intermediate levers *2* and *9*, then a voltage is fed to the automatic control system of the machine. This energizes an electromagnet, which switches off the machine, or switches over from roughing to finishing feed.

Contacts *3* are held by springs *1* and *10* against adjusting screws *4* by means of which the gauge is set up.

A dial indicator, actuated by spindle *11*, is mounted in the body of the device. As the spindle moves downwards, the hand of the dial indicator shows the amount of its travel. This enables the operation of the gauging device to be continually checked. Two lamps are provided on the body of the device: one red and one green. The red lamp lights up when the contacts are closed to energize the electromagnet, which switches off the machine or changes over the feed.

This automatic gauging system frees the worker from the necessity of repeatedly stopping the machine to check the size of the work being ground. Thus, he need not stand by the machine throughout the grinding operation, but can operate a number of machines at one time, so that his output is correspondingly increased.

CHAPTER

5

Aspects of engineering mechanics

5-1. TYPES OF MOTION

The grinding of a shaft in a cylindrical grinding machine occurs as the result of the rotary motion of the grinding wheel and the complex motion of the shaft being ground: the latter rotates between centres relative to the table, and reciprocates together with the table.

To establish the basic rules of motion, let us single out any point on the surface of the shaft and follow its motion. Let us imagine a plane on the table of the grinder, perpendicular to the axis of rotation of the shaft, and passing through the given point. During the rotation of the shaft, the point will describe a circular path in this plane, and this is called the path of motion of the given point. If rotation of the shaft is stopped, and the longitudinal motion of the table is engaged, then the path of motion of the point would be a straight line. With simultaneous rotation of the shaft between centres and longitudinal movement of the table, the point will describe a helix.

During the grinding process, when steady motion has been established, the given point will travel uniformly, with a velocity equal to the path described in one second. Thus

$$v = \frac{S}{t}$$

where S is the length of the path described by the point in the time t.

If the path is measured in mm and the time in seconds, the speed will be expressed in mm per sec.

The speed of motion of any point on the surface of a revolving workpiece can be determined by two methods. Let

the distance of the given point from the axis of rotation be equal to r, and the time required for the component to make one revolution be equal to t. The path traversed by this point in one revolution of the workpiece will be

$$S = 2\pi r$$

hence

$$v = \frac{2\pi r}{t}$$

The speed of rotation thus obtained is called the linear velocity and it refers only to points lying at a distance r from the axis of rotation.

The speed of rotation is frequently determined by the angle through which a given point has turned about its axis of rotation in one second. The speed thus determined is called the angular velocity of rotation. To determine the angular velocity, the following equation is used

$$\omega = \frac{\varphi}{t}$$

where φ = angle through which the point has revolved, degrees in t sec

ω = angular velocity, deg per sec.

The angular velocity of points of a rotating body does not depend on their distance from the axis of rotation.

The angular velocity can also be measured by the number of revolutions per second or per minute, and is then denoted by the letter n. If the linear velocity v of a point on the surface of a rotating body of diameter d is known, its rotational speed can be determined

$$n = \frac{1{,}000 \times 60v}{\pi d} \text{ rpm}$$

and, conversely, from the rotational speed (rpm) and the diameter of the revolving body, the linear velocity of a point on its surface can be determined

$$v = \frac{\pi dn}{60 \times 1{,}000} \text{ m per sec}$$

The above cases of rotary motion represent only a particular case of the motion of a body. A fuller investigation of the various possible forms of motion is the concern of the section of engineering mechanics called kinematics.

5-2. A FORCE

Elements Determining a Force. The action of one body on another, as a result of which the state of motion of each is altered, is called a force.

Forces exerted by one body on another are always characterized by the *direction*. For instance, the force of gravity is directed towards the centre of the Earth, i.e., it is vertical; the oil in a hydraulic cylinder acts on the piston along the axis of the cylinder, etc. Thus, direction is the first element determining a force.

The second element determining a force is its *magnitude*. The greater the mass of the body, the greater will be its gravitational effect; the greater the pressure in a hydraulic system, the greater will be the force pushing the piston. The unit of weight, the kilogram, is used to measure the magnitude of a force.

Apart from its magnitude and direction, the force is also determined by the *point of application*. For instance, the magnitude of the force required to lift a load by means of a lever depends on the point on the lever at which it is applied.

Addition of Forces. All three elements determining the force can be very conveniently understood from a graphical representation, in which the force itself is represented in the form of a section of a straight line, called a *vector*. The magnitude of this vector, in a definite scale, determines the magnitude of the force. The origin of the vector corresponds to the point of application of the force, and the arrowhead at the end of the vector indicates the direction of the force.

In Fig. 45, vector AB shows the force applied at point A and acting at an angle of 30° to the horizontal plane. At a vector length of $AB = 50$ mm, and a scale of 5 mm = 1 kgf, the represented force $P = 10$ kgf.

Two forces acting along a single straight line can be replaced by one force equal to their algebraic sum and acting in the same direction as that of the larger of the two. Hence, if two forces are equal in magnitude and act along one straight line in opposite directions, they will be balanced.

In order to add two forces applied at one point and acting at an angle to each other, it is sufficient to construct a parallelogram (Fig. 46), the sides of which correspond in magnitude and direction to the forces in question. The diagonal of the parallelogram obtained will be the resultant of the given forces.

Stability of Equilibrium. The force of attraction of the Earth, i.e., the force of gravity, acts on each part of a body. All these forces are practically parallel, and their resultant

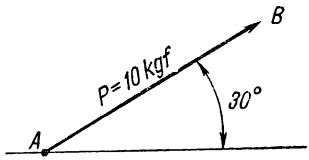


Fig. 45. Graphical representation of the magnitude and direction of a force

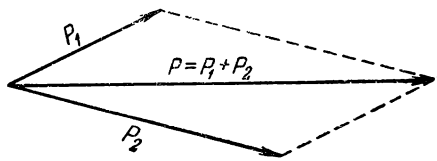


Fig. 46. Addition of forces

is the weight of the body under consideration. The point of application of this resultant (gravity) is called the *centre of gravity of the body.*

The position of the centre of gravity influences the stability of the body. If the centre of gravity of a body, supported at a point under equilibrium conditions, does not occupy the lowest possible position, then the equilibrium of the body will be unstable and, conversely, a body will be in a stable equilibrium position when its centre of gravity occupies the lowest possible position.

Moment of a Force. The force required to screw a nut down with a wrench is the smaller, the longer the wrench. This means that the rotary action of a force relative to a given axis depends not only on the magnitude and direction of the force, but also on the distance of the line of action of the applied force from the axis of rotation. For this reason, in mechanics, the rotary action of a force is determined in terms of its moment. The moment of the force P relative to the point O (Fig. 47) is equal to

$$M = P\varrho$$

where ϱ is the perpendicular dropped from point O to the line of action of force P.

The point O, relative to which the moment of the force is taken, is called the *centre of moment*, and the distance of the centre of moment from the line of action of the force

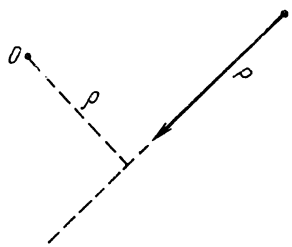


Fig. 47. Moment of a force

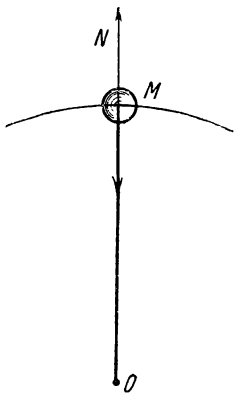


Fig. 48. Direction of centrifugal and centripetal forces

is called the *arm of the force*. Thus, the product of the force and its arm is called the moment of the force relative to the point.

Centrifugal and Centripetal Forces. Fig. 48 represents a sphere M, connected to a point O by a wire MO. The sphere is rotated about an axis passing through O. If, due to its lack of rigidity, the wire initially had arandom form, it will straighten out under tension due to the rotation of the sphere. The greater the rotational speed of the sphere, and the greater its mass, the greater the tensile force in the wire. This force is caused by the rotation of the sphere and is called the *centrifugal force*.

The magnitude of the centrifugal force can be determined from the formula

$$N = \frac{mv^2}{R}$$

where m = mass of the rotating sphere
v = its linear velocity
R = distance from the centre of gravity of the sphere to the axis of rotation.

The wire acts on the sphere, holding it at a fixed distance from the centre, with the same force with which the sphere acts on the wire. The force holding the rotating sphere at a fixed distance from the centre is called the *centripetal force.* The latter is equal in magnitude to the centrifugal force, but acts in the opposite direction.

5-3. FRICTION AND ITS ROLE IN ENGINEERING

When one body moves along the surface of another, a force is set up in opposition to the movement. This is called the *frictional force.*

The frictional force can assume two forms. In the rotation of the spindle of a grinding wheel in bronze bearings, *sliding friction* arises. In the course of sliding friction, each point on the spindle successively makes contact with a countless number of points on the bearing, these points lying along an annulus coincident with the path of the point.

A different situation exists during the movement of a wheel along a rail. In this case, each point on the surface of the wheel coincides with only one point on the rail (in one revolution of the wheel). Such a motion is called *rolling*, and the resistance arising during rolling is called the *rolling friction.* The force of rolling friction is considerably less than the force of sliding friction.

The effect of frictional force is usually undesirable, since the increased resistance to motion results in an increased expenditure of energy, as well as in heating and increased wear of the rubbing components. Thus, mechanisms are usually designed to substitute rolling for sliding friction as much as possible.

However, very frequently, friction shows itself as an advantageous factor, for instance, in all kinds of braking mechanisms. In these cases, sliding friction is made use of, and the materials chosen for the rubbing surfaces are selected so as to provide a high frictional resistance, i.e., they possess a large *coefficient of friction.*

5-4. PRINCIPLES OF MECHANISMS AND MACHINES

A grinding machine produces useful work by machining workpieces. The mechanical energy required to drive the grinding wheel and the workpiece to be ground is obtained from electric motors, which consume electrical energy produced by generators. The result of the consumption of these various forms of energy is visible as useful work.

Each machine consists of a combination of mechanisms. A system of mobile bodies connected with each other (called link members) which accomplish a given motion is called a *mechanism.*

In grinding machines, as well as in other metal-cutting machine tools, mechanisms which transmit motion are widely used, e.g., belts, gears, worm gears and friction transmissions, etc.

Work and Power. To displace a load along a horizontal plane, a force must be applied which is determined essentially by the frictional resistance. If the speed of movement of the load is uniform, then a constant force is required to keep it moving.

Let us assume that the magnitude of the applied force is equal to P, and the path which has been covered by the load under the action of this force is equal to S. Then the product PS will be the quantity of work W, expended on the displacement of the given load. The *unit of work* is 1 kgf-m, i.e., the work done by a force of 1 kg along a path of 1 m.

The effectiveness of a source of energy is estimated in terms of the quantity of work which it performs in one second. This is known as its power rating.

The *unit of power* is the kgf-m per sec. Frequently, however, power is measured in larger units, namely: the metric horsepower, equal to 75 kgf-m/sec, or the kilowatt (kW), equal to 102 kgf-m/sec.

Efficiency. In any machine, the total work (W_{mf}) done by the motive force is expended partly in the performance of useful functions (for instance, overcoming the resistance of a metal to cutting) and partly in overcoming inevitable but unproductive resistances (for instance, the frictional resistance). If the productive portion of the work done is

denoted by W_{pr} and the unproductive portion by W_{unpr} then it is obvious that

$$W_{mf} = W_{pr} + W_{unpr}$$

Dividing both sides of this equation by W_{mf} we obtain

$$1 = \frac{W_{pr}}{W_{mf}} + \frac{W_{unpr}}{W_{mf}}$$

The ratio $\frac{W_{pr}}{W_{mf}}$ gives the proportion of the expended energy applied productively, and is called *efficiency*. Since there are always frictional and other resistances present in mechanisms, efficiency will, in any machine, be less than unity.

5-5. DEFORMATION

Let us imagine a straight rod gripped at one end in a vise. If a weight is suspended from the other end, the rod will bend. The extent to which the rod bends will vary within wide limits, depending on the weight, the cross section of the rod and the distance between the weight and the vise. The change of shape of a body or of its dimensions under the action of forces applied to it is called the *deformation*, or *strain*, of the body.

If, when the action of the force has ceased, the shape of the body is restored, then such deformation is called *elastic*. If, however, the body remains deformed after the force has ceased to act, then the deformation is called *permanent* or *plastic*.

Distinction is made between the following types of deformation.

Tensile and Compressive Deformation. Such deformation is experienced by a body to which forces are applied along its axis, as, for instance, the shank of a bolt tightened by a nut, the ropes of hoisting mechanisms, etc.

The magnitude of deformation in tension is the greater, the greater the magnitude of the applied force and the length of the body under tension, and the smaller its cross section.

Torsional Deformation. As an example of a body experiencing torsional deformation, a shaft can be taken, one end of which carries the driving pulley, and the other, a

driven pulley. Under the action of two moments acting in opposite directions, the rod is twisted through a certain angle, the magnitude of which depends on that of the torsional moments and on the cross section of the shaft.

Bending Deformation. Various types of girders, possessing one or several supports and loaded either by concentrated or uniformly distributed forces, experience bending deformation.

In practice, *complex deformations* of a body also exist, i.e., when a machine component is subjected to several types of deformation. For instance, the feed rod of a lathe experiences torsional and bending deformation simultaneously.

CHAPTER

6

Grinding wheels

6-1. TYPES OF CUTTING TOOLS AND THEIR ACTION

The machining of components in metal-cutting machine tools is carried out by removing the excess metal, or stock, from blanks in the form of chips, using various types of cutting tools: single-point tools, drills, milling cutters, core drills, reamers, taps, broaches, grinding wheels, abrasive cloth, abrasive paste, etc.

Single-point tools, drills, milling cutters, core drills, reamers, taps and broaches are made of alloy tool steels and high-speed steels, or they may be tipped with cemented carbides, and are provided with sharp cutting edges.

Grinding wheels, abrasive sticks and abrasive cloth consist of individual abrasive grains, held together by a bond. The abrasive grains have sharp edges, which cut the metal on making contact with the surface to be machined.

The removal of a chip by a metal or abrasive tool is identical in principle and requires that the cutting edge or edges of the tool be indented into the surface of the workpiece being machined by the application of a definite force to the tool. Upon movement of the tool, the elements of the chip are sheared or split from the surface. Though this much is common to all metal-cutting processes, cutting by means of single-point tools, milling cutters, drills, grinding wheels and other tools has its own peculiarities. We shall first consider the cutting process of the simplest cutting tool, the single-point tool, from which the other cutting tools are derived.

The Action of a Single-point Tool. Machine tools of the lathe group (engine and turret lathes), as well as planers, shapers and slotters, use single-point tools.

During the cutting process (Fig. 49), the point of the tool—the face and flank (*OA* and *OE*, respectively)—cuts like a wedge into the material of the workpiece under the action of force *P* applied to either the tool or workpiece. The tool face compresses a layer of metal and, by overcoming the internal forces of cohesion, causes particles of the

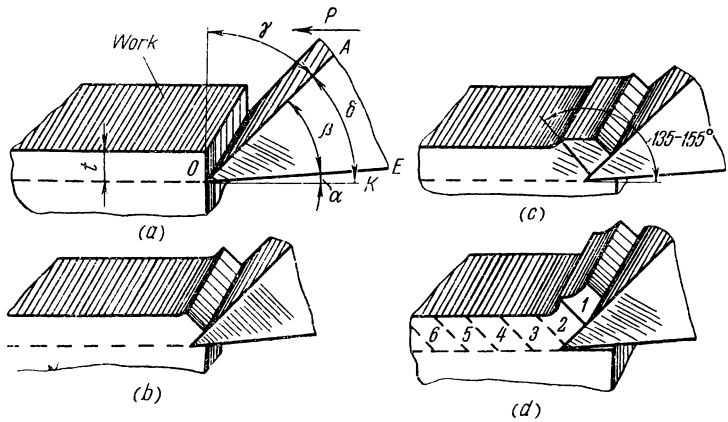


Fig. 49. The metal-cutting process:
a, *b*, *c* and *d*—initial and subsequent moments in cutting

metal (chip elements) to shear off and slide upwards along the face of the tool.

Fig. 49*d* shows six chip elements that are sheared in succession at an angle from 135 to 155°. If the force *P* is applied continuously, the tool will consecutively shear off chip elements, thereby removing a layer of metal, of the depth *t*, from the surface of the workpiece.

The flank *OE* of the tool makes the angle *EOK* with the machined surface of the workpiece. This angle is provided to reduce friction between the tool flank and the surface of the workpiece.

The angles formed between the surfaces of the tool and the workpiece (Fig. 49*a*) have the following names:

γ (gamma)—rake angle;
β (beta)—lip angle;
α (alpha)—relief angle;
δ (delta)—cutting angle.

Practically, the force required in the compression of the metal in cutting depends on angle δ. The smaller δ, the less the force required.

The lip angle of the tool, β, is assigned according to the material being machined and the material of the tool. The selection of the cutting speed and the surface finish obtained on the work depend upon the lip angle.

Types of Chips. The chip formed in machining hard metals consists of separate elements, quite firmly bonded together in steps. This is known as a *sheared chip* (Fig. 50*a*).

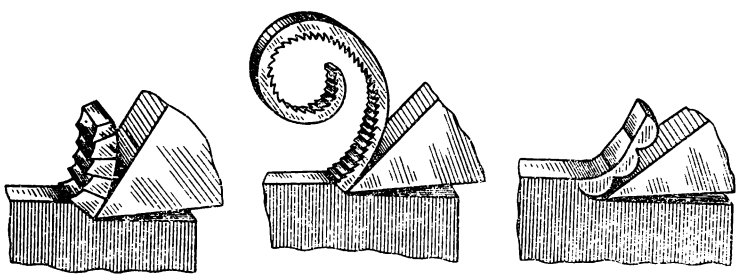


Fig. 50. Types of chip:
a—sheared chip; *b*—continuous chip; *c*—discontinuous or segmental chip

In machining ductile metals (e.g., copper, soft steel), the elements of the chip are firmly bonded to each other. The upper side of such a chip has fine notches while the lower side, which slides over the tool face, is smooth and shiny. This is called the *continuous chip* (Fig. 50*b*).

When brittle metals are machined, a *discontinuous*, or *segmental*, chip is formed (Fig. 50*c*). The latter is characterized by the fact that its elements, which resemble flakes of irregular shape, are separated from each other. In contrast to the sheared chips, discontinuous chips have an irregular surface on the underside, adjacent to the tool face, and a smooth surface on the opposite side. Chips of this type are formed in machining cast iron or bronze.

During the formation of discontinuous chips, nonuniform loads act on the tool. The same nonuniform load is transmitted to the workpiece, fixture, and machine tool.

The resulting machined surface will be rough, with ridges and valleys.

The least variation in the forces acting on the tool, workpiece, machine tool and the fixture will be obtained when a continuous chip is produced; the machined surface is also smoother in this case.

As the cutting angle δ and the depth t of the metal layer being removed are decreased, and the cutting speed is increased, the chip will approach the continuous type in form. The application of a cutting fluid (coolant) has the same influence on the form of the chip.

After the removal of the chip, the properties of the surface layer of the machined metal are changed somewhat; its structure becomes denser and harder, and its ductility decreases. This effect is called *work-hardening* of the metal. The more ductile the metal, the greater will be the degree of work-hardening and the thickness of the work-hardened surface layer.

Operation of a Milling Cutter. Milling is a type of machining performed by a tool which is called a *milling cutter.* The latter has several cutting teeth, each of which is a single-point tool in principle. The teeth of a milling cutter have the same angles as a lathe tool.

During the milling process, the milling cutter rotates with the spindle of the machine, while the workpiece, which is clamped on the work table, is fed with the latter past the rotating cutter. Each tooth of the cutter in turn cuts into the blank and removes a chip from the machined surface. The layer of metal t, which is removed in one pass, is called the depth of cut. In Fig. 51, the milling process and the cutter teeth angles are illustrated.

Operation of a Grinding Wheel. The performance of a grinding wheel can be compared to that of a milling cutter. The abrasive grains of the grinding wheel make periodic contact with the machined surface of the component similarly to the teeth of a milling cutter. A particle of metal, the chip, is removed as the result of each such contact (Fig. 52).

Each abrasive grain represents a miniature single-point tool. The number of such tools depends on the size of the grains and the diameter and width of the wheel. The number

of abrasive grains in the wheel varies between some tens of thousands in wheels of small diameter and hundreds of

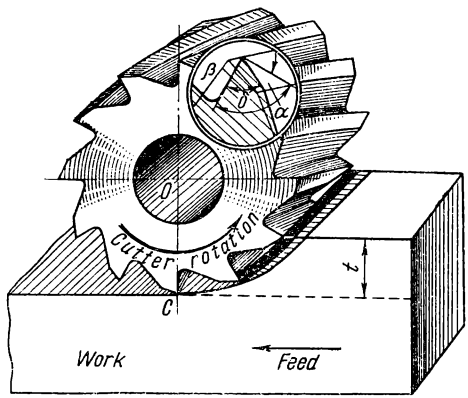


Fig. 51. Milling process

thousands for wheels of large diameter and width. For instance, a wheel 400 mm in diameter, 40 mm wide and of

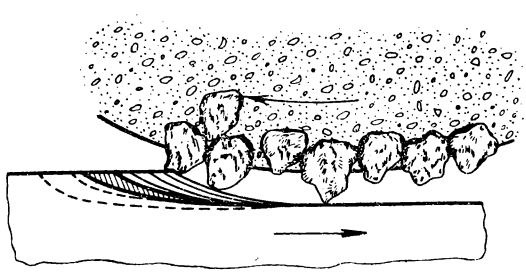


Fig. 52. Grinding with abrasive grains

grain size 50 has not less than 200,000 cutting grains, distributed on the periphery of the wheel.

The particles of metal removed by the abrasive grains are of irregular shape, since the grains themselves differ in shape and distribution relative to the surface being machined.

These chips are very small in size. Under a microscope, however, their similarity to the chips obtained in turning, milling and planing operations can be seen. This shows that cutting with abrasive tools is subject to the same laws as cutting with steel and carbide-tipped edged tools. During grinding, the abrasive grains cut into the surface to be machined with their sharp edges, and remove chips after overcoming the cohesive forces between the particles of the material.

Grinding has certain features that differ substantially from milling. For instance, in contrast to the teeth of a milling cutter, the grains of the wheel are irregularly shaped, tend to be rounded at the points, and are randomly distributed along the wheel. This leads to a constant change of the rake angle, which as a rule is negative (obtuse). Grinding consists of a summary, very shallow mass cutting of the workpiece material by means of individual cutting grains. The removal of a chip by an individual cutting grain occupies a very short time (0.0001-0.00005 sec), i.e., it is practically instantaneous, but owing to the large number of grains, chip formation is continuous when the whole wheel is considered.

During grinding, dulled grains are torn out of the wheel, owing to the increased load on them. As a result, new, sharp grains are continuously being exposed. Thus, in contrast to milling cutters, grinding wheels may be regarded as self-sharpening.

6-2. ABRASIVE MATERIALS

For the manufacture of abrasive tools, fine grains of artificial and natural abrasive materials are used. In order to cut into the material to be ground, for instance, hardened steel, hard cast iron, etc., the material used to make the cutting tool must be harder than the material which is to be machined.

An abrasive tool must have sharp cutting edges, and should possess high stability and strength at elevated temperatures.

The following are used as materials for abrasive tools:

(a) minerals of natural derivation: diamond, garnet, quartz, emery, corundum, lime, chromium oxide, iron oxide;

(b) minerals of artificial derivation: aluminium oxide, silicon carbide, boron carbide, monocorundum, boron-silicon carbide.

The hardness of these materials is determined according to Mohs' hardness scale, as used in mineralogy. The Mohs hardness of diamond is 10 units.

Diamond is one of the three allotropic forms of carbon (coal, graphite and diamond). It is a rare, expensive mineral, possessing a greater hardness than any other known natural or synthetic material except boron-silicon carbide.

Diamonds used in industry are called *industrial diamonds*, and are widely applied in the dressing of grinding wheels, the manufacture of abrasive wheels and stones, for sharpening cutting tools, in drilling oil wells, etc.

At the present time, synthetic diamonds are used for these purposes. Synthetic diamonds have rougher surfaces and edges. For this reason, wheels made of them cut faster than those made of natural diamonds by an average of 35%, and in special cases by 100%.

Garnet is a chemical compound of aluminium and the silicates of magnesium and manganese.

Quartz, which is mined in the form of pebbles and sand, is a chemical compound of silicon and oxygen (SiO_2).

Emery is mined, and consists of a mixture of corundum and magnetite (iron ore). The content of pure corundum in emery is 40 to 50%. Emery is nonuniform, and is not as hard as other abrasive materials, and hence its application is limited.

Corundum is a mineral consisting of aluminium oxide (Al_2O_3 from 70 to 92%), with iron oxide, mica, quartz, etc., as impurities. It occurs in the form of sapphire, rubies, and ordinary corundum. Ordinary corundum is used for the manufacture of grinding wheels. The corundum grains are very hard and, on being crushed, form a conchoidal fracture with sharp edges. Under conditions of heavy grinding, however, these rapidly lose their shape, i.e., they are dulled.

Aluminium oxide abrasives (synthetic corundum) are produced in an electric furnace by melting materials rich in aluminium oxide (for instance, bauxites and alumina). Aluminium oxide abrasives are available in three types:

1. Standard aluminium oxide, which is produced by the reduction of molten bauxites. It contains Al_2O_3 in quantities not less than 87%, and has a colour ranging from greyish brown to dark brown.

2. White aluminium oxide, which is produced by remelting pure alumina. It contains not less than 97% Al_2O_3, and is of white or light pink colour.

3. Monocorundum. Depending on the proportion of impurities, it is subdivided into two types: (a) one containing between 96.5 and 97.4% Al_2O_3 and (b) one containing 97.5 to 98.5% Al_2O_3.

Silicon carbide (SiC) is a chemical compound of silicon and carbon. It is produced in electric furnaces at a temperature of 2100°-2200°C, from quartz sand and coke. Silicon carbide grains have a dark blue and green tinge with a metallic lustre and temper colours.

Silicon carbide is a very hard material (next to diamond in hardness). Its grains have sharp cutting edges which can easily penetrate into the material being machined, and can withstand temperatures up to 2050°C. According to its colour, silicon carbide is classified as either black or green.

Boron carbide is made from commercial boric acid and low-ash carboniferous material (for instance, petroleum coke, pitch coke, carbon black, etc.) fused at a temperature of 2000°-2350°C in electric furnaces.

Borosilicon carbide is known under the name of B-1 powder, and is a new hard material originally produced at the U.S.S.R. Abrasives and Grinding Research Institute. In contrast to boron carbide, it does not contain the harmful impurity graphite. It is used, in the form of a finely divided powder, for abrasive pastes.

Iron oxide is produced by treatment of iron vitriol with oxalic acid. It is used in the form of a powder.

Chromium oxide is a powder of dark green colour and is produced from potassium bichromate by the addition of sulphur.

Lime is a natural, soft and fine polishing material, better known under the name of French chalk. It is produced by calcining limestone and purifying the product from sand and clay by elutriation. The fields of application of the above abrasive materials are given in Table 5.

Table 5

Applications of Abrasive Materials in Grinding

Name of abrasive material	Form in which applied	Type of work done
Diamond	Grains and powders in loose (unattached) form, in form of grinding wheels and diamond tools	Grinding, cutting and polishing diamonds, rubies, glass and other materials difficult to machine Dressing and truing grinding wheels. Grinding carbide-tipped tools
Natural corundum (more than 90% Al_2O_3)	Grains for special-purpose grinding wheels. Powders, micron powders and abrasive pastes	Grinding balls for ball bearings. Grinding and lapping metals, glass and other materials
Emery	Abrasive powders and pastes	Lapping
Garnet	Loose grains	Grinding glass
Quartz	Grains for grinding wheels and abrasive cloth	Regulating wheels for centreless grinding. Sanding wood, ebonite, leather, etc.
Lime	Micron powders	Finish polishing of various workpieces
Chromium oxide	Micron powders and pastes	Lapping workpieces of steel, nonferrous metals; lapping tools; polishing metals, glass, etc.
Iron oxide	Micron powders and pastes	Polishing glass, workpieces of steel and nonferrous alloys
Standard aluminium oxide (up to 93% Al_2O_3)	Grains and powders for organic-bonded wheels. Powders	Finish grinding structural and carbon steel in as-received and hardened conditions. Finishing metal articles with powders

Table 5 (Continued)

Name of abrasive material	Form in which applied	Type of work done
Standard aluminium oxide (91-92% Al_2O_3)	Grains for organic-bonded wheels. Powders	Rough grinding iron and steel castings and forgings, and dressing of welded steel joints. Finishing metal articles with powders
Standard aluminium oxide (up to 93% Al_2O_3)	Grains for variously bonded abrasive tools	Grinding structural and carbon steels in as-received and hardened conditions, alloy steels, malleable and grey iron, hard bronze
Standard aluminium oxide (up to 95% Al_2O_3)	Grains and powders for variously bonded abrasive tools. Wheels for high-velocity grinding	Grinding hardened carbon and alloy steels, high-speed steels and their substitutes, sharpening tools
White aluminium oxide (up to 97% Al_2O_3)	Grains and powders for organic-bonded abrasive tools. Powders	Grinding and lapping alloy and hardened steels
White aluminium oxide (98-99% Al_2O_3)	Grains, powders and micron powders for variously bonded abrasive tools. Wheels for high-velocity grinding	Grinding and lapping alloy and hardened steels. Sharpening and lapping cutting tools
Monocorundum (96.5-97.4% Al_2O_3)	Abrasive powders and pastes	Lapping hardened carbon and alloy steels
Monocorundum (97.5-98.5% Al_2O_3)	Grains and powders for variously bonded abrasive tools	Grinding alloy, case-hardened, hardened and nitrided steels. Sharpening and lapping cutting tools
Black silicon carbide (95-97% SiC)	Grains and powders	Grinding hard metals and nonmetals with loose grains

Table 5 (Continued)

Name of abrasive material	Form in which applied	Type of work done
Black silicon carbide (97-98% SiC)	Grains and powders for variously bonded abrasive tools	Grain size 16-36: grinding cast iron, copper, aluminium, glass, porcelain, stone, ebonite, etc. Grain size 46-80: grinding hard and brittle materials. Sharpening carbide-tipped tools
Green silicon carbide (98-99% SiC)	Grains and powders for variously bonded abrasive tools. Powders and micron powders Grains for variously bonded abrasive tools	Precision grinding and lapping alloy and hardened steels and nonmetallic materials of great hardness Grinding cemented carbides, sharpening ceramic-tipped tools. Grinding very hard nonmetallic materials
Boron carbide	Abrasive powders and pastes	Lapping cemented-carbide and ceramic cutting tools. Grinding and lapping cemented-carbide ring gauges, grinding precision industrial and watch jewels of synthetic rubies; drilling and lapping bearings of special measuring instruments, etc.
Boron-silicon carbide	Brand A—powders and micron powders, M3 or coarser, for organic-bonded abrasive tools	Precision grinding and lapping brittle materials: industrial rubies, quartz, optical glass, semiconductors, cemented carbides, etc.
	Brand B—grinding powders and micron powders, M14 or coarser, for organic-bonded abrasive tools	Grinding, cutting and lapping cemented carbides and special metal alloys, lapping surfaces of workpieces of very hard nonmetals

6-3. GRAIN SIZE OF ABRASIVE MATERIALS

In wheels, stones, sticks or powders used for grinding, abrasive grains of definite sizes are used so that the chips removed by them are uniform. To remove heavier chips, grinding wheels with coarse grains are used, while finer grinding is performed with wheels of finer grain size.

To prepare the abrasive material for use in a tool, large pieces of it are broken up in crushers until grains of the required sizes are obtained. After crushing, the grains are separated from impurities, and subsequently undergo chemical and thermal treatment. The grain size of abrasive materials is determined by the mesh sizes of two consecutive screens through which sifting or analysis of selected abrasive grains (powder) is carried out. Grain sizes are classified in accordance with the following numerical scale: 200; 160; 125; 100; 80; 63; 50; 40; 32; 25; 20; 16; 12; 10; 8; 6; 5; 4; 3; M40; M28; M20; M14; M10; M7 and M5.

The grain sizes of abrasive materials are given, in Soviet standard specifications, in terms of the mesh of the sieve, in hundredths of a millimetre (a previous standard specified sizes as the number of meshes of the sieve to the linear inch).

Table 6 can be used for the conversion of grain sizes from the metric to the inch system, and vice versa.

In the table, each size is specified in terms of two numbers, the larger of which corresponds to the smallest mesh through which the grains will pass, while the smaller corresponds to the largest mesh through which they will not pass.

Abrasive materials are divided, according to their grain size, into three groups with the following grain-size numbers:

(1) grinding grains—200, 160, 125, 100, 80, 63, 50, 40, 32, 25, 20 and 16;
(2) grinding powders—12, 10, 8, 6, 5, 4 and 3;
(3) micron powders—M40, M28, M20, M14, M10, M7 and M5.

Micron powders are denoted by the letter M and a number which specifies the largest grain size in microns.

The grain size of micron powders is determined by measuring, through a microscope, the width of the largest grain

Table 6

Grain Size of Abrasive Materials in the Metric and Inch Systems

Grain size		Grains passing through sieve with screen		Grains retained on sieve with screen	
According to U.S.S.R. standard (in 0.01 mm)	In inch system (grit)	Nominal mesh aperture, microns	No. of screen	Nominal mesh aperture, microns	No. of screen
200	10	2,500	2.5	2,000	2
160	12	2,000	2	1,600	1.6
125	16	1,600	1.6	1,250	1.25
100	20	1,250	1.25	1,000	1
80	24	1,000	1	800	08
63	30	800	08	630	063
50	36	630	063	500	05
40	46	500	05	400	04
32	54	400	04	315	0315
25	60	315	0315	250	025
20	70	250	025	200	02
16	80	200	02	160	016
12	100	160	016	125	0125
10	120	125	0125	100	01
8	150	100	01	80	008
6	180	80	008	63	0063
5	230	63	0063	50	005
4	280	50	005	40	004
3	320	40	004	—	28

visible in the field of vision of the microscope. The grain sizes of grinding powders Nos. 4 and 3 are measured by a combined method, i.e., grains larger than 40 microns are determined by the sizes of the sieve mesh aperture, and finer ones by linear measurements of grains under the microscope.

The selection of the wheel with respect to grain size depends upon the type of grinding required, how much material must be removed at each pass, and the surface finish and machining accuracy required. Wheels with coarse grains remove more metal in grinding, increase the output, but, at the same time, score the surface of the workpiece being ground. They are only used for rough grinding.

Fine-grained wheels are used for finishing operations. In Table 7, recommendations are given for the selection of suitable grain sizes of abrasive materials.

Table 7

Grain Size of Abrasive Materials Used for Various Types of Work

Grain size		Type of work
According to U.S.S.R. standard (in 0.01 mm)	In inch system (grit)	
125-80	16-24	Dressing welded joints, snagging castings, etc.
50-40	36-46	Rough grinding. Rough sharpening of cutting tools
40-16	46-80	Semifinish and finish grinding; grinding high-speed and carbide-tipped tools
16-12	80-100	Finish grinding (e. g., races of bearing rings), sharpening small cutting tools
12-4	100-280	Thread grinding
6-5	180-230	Lapping multi-edge tools
6-3	180-320	Finish grinding

6-4. BONDING MATERIALS

After sorting the abrasive grains according to their size, they are mixed with a bonding material and compacted into a grinding wheel of definite shape and size.

Bonding materials are classified as inorganic and organic. Inorganic materials include vitrified, silicate and oxychloride bonds, and organic ones include resinoid and rubber bonds.

The vitrified bond consists of refractory clay and feldspar. The mixture of bonding material and abrasive grains is compacted or cast. Cast wheels are more brittle and porous than compacted ones. Various degrees of hardness (grade) may be imparted to a wheel by selecting the composition of the bonding material. Different porosities are obtained by using different compacting procedures.

A vitrified bond is temperature-stable, and, in addition, possesses a high chemical stability; it is therefore possible to use various coolants in grinding. Grinding wheels of stand-

ard aluminium oxide, white aluminium oxide and black or green silicon carbide are made with a vitrified bond.

The vitrified bond allows a wheel to be run at a speed up to 50 m per sec. Thin wheels with a vitrified bond cannot withstand lateral loads.

The silicate bond consists of liquid glass. This bond does not hold the grains firmly in the wheel, since liquid glass adheres poorly to the abrasive grains. Silicate-bonded wheels are used when a workpiece is to be ground dry but, at the same time, the surface of the workpiece must not be overheated. Upon being heated, the bond easily releases dulled grains from the surface of the wheel and new sharp grains are exposed.

The magnesium oxychloride bond consists of caustic magnesite and magnesium chloride (Sorel cement). It is used for the manufacture of emery and natural corundum wheels.

Oxychloride-bonded wheels are nonuniform, they wear out rapidly and unevenly, i.e., they have a low service life. They are very sensitive to dampness, under the action of which they are destroyed, as well as to elevated temperatures.

The resinoid bond consists of bakelite resin in the form of a powder or of bakelite lacquer. This is the most widely used among the organic bonds.

The resinoid bond is used with all types of abrasive materials. Wheels made in this way possess high strength and elasticity, they are temperature-stable, but their porosity is lower than that of vitrified wheels.

Resinoid-bonded wheels operate at speeds of 35 to 70 m per sec, and may be as thin as 0.18 mm. Such wheels are used as an alternative to saws (abrasive cutting).

For heavy work, where the cutting temperature attains more than 300°C, the bond burns out quickly and the grains crumble out. Under the action of alkaline liquids, the bakelite bond is partly destroyed, and hence the application of grinding fluids containing more than 1.5% soda is not to be recommended.

A rubber bond consists essentially of rubber. For the manufacture of wheels, the abrasive material is mixed with rubber, as well as with small quantities of sulphur and other components. Vulcanization of the abrasive mixture is carried out in special moulds held in a press. The rubber becomes

hard and elastic. At a temperature of above 150°C, however, the rubber softens and begins to burn out.

Rubber wheels are strong and elastic, and may therefore be used for grooving and cutting-off operations. They possess good polishing properties and may be used with alkaline grinding fluids. In the grinding of high-carbon steels, resinoid- and rubber-bonded wheels are used to avoid burns and cracks. Rubber-bonded wheels are more elastic than resinoid-bonded ones, but their porosity is lower.

At the present time, abrasive factories have adopted the manufacture of wheels with fabric linings. The abrasive powder is mixed with bakelite resin and placed into a mould between layers of fabric. On compressing the mould and heating, monolithic abrasive wheels are obtained which are reinforced by the linings. Such wheels possess a high strength and can be operated at a speed of 70 m per sec.

6-5. HARDNESS OF GRINDING WHEELS

The hardness, or more properly grade, of a grinding wheel characterizes the strength with which the bonding material holds the abrasive grains. It has no reference to the hardness of the abrasive and is simply the resistance which the bond exerts against the grinding stresses which tend to tear the grains out of the wheel face. The harder the wheel, the greater the force required to tear out a grain from the bond. The hardness, or grade, of abrasive tools is designated in the Soviet Union as shown in Table 8.

Table 8

Hardness, or Grade, of Abrasive Tools

Symbol	Hardness (grade)	Hardness group
M	Soft	M1, M2, M3
CM	Medium soft	CM1, CM2
C	Medium	C1, C2
CT	Medium hard	CT1, CT2, CT3
T	Hard	T1, T2
BT	Very hard	BT1, BT2
ЧТ	Extremely hard	ЧТ1, ЧТ2

The numerals 1, 2 and 3 at the right of the letter notations characterize the grade of the tool in the order of increasing hardness.

Abrasive tools of all hardnesses are made with the vitrified and resinoid bonds, but in the case of rubber-bonded wheels, the only hardnesses available are CM1, CM2, C1, C2, CT1, CT2, CT3, T1 and T2. For grinding hard materials, softer wheels are used, while soft materials are more expediently ground with hard wheels.

The hardness (grade) of a grinding wheel may be determined by three methods: (1) sand-blasting, (2) ball indentation and (3) drilling a hole.

The sand-blasting method consists in directing a jet of quartz sand under pressure onto the surface of the wheel being tested. This leaves a depression on the surface. From the depth of the depression, the hardness of the wheel can be estimated. This method is used for determining the hardness of vitrified and resinoid-bonded wheels of grain size from 10 to 100 grit, according to the inch system (from 200 to 12 in hundredths of a millimetre). In the second method, a hardened ball is pressed into the surface of the wheel under a given load. The indentation produced in a soft wheel is deeper than that in a hard one. The hardness of the wheel is estimated in terms of the depth of the depression. This method is used for resinoid- and rubber-bonded wheels of grain size from 100 grit (in the inch system) to M14 (from 12 in hundredths of a millimetre up to M14).

The third method consists in drilling a hole of a given depth with a special drill under a constant pressure. The hardness of the wheel is estimated by the number of revolutions of the drill required to reach the specified depth.

This method is used for rubber-bonded wheels of grain size from 24 to 120 grit in the inch system (from 80 to 10 in hundredths of a millimetre).

6-6. STRUCTURE OF A GRINDING WHEEL

With reference to grinding wheels, the term *structure* is to be understood as internal structure, i.e., the numerical ratio and relative arrangement of the grains, bond and pores in the body of the wheel. The pores are small voids in the

material of the wheel, whose function is to receive the chips produced in grinding. The chips should not, however, be

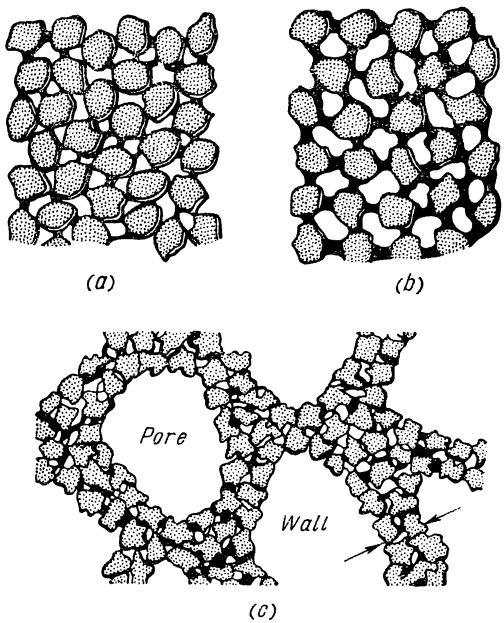


Fig. 53. Structures of grinding wheels:
a—dense; *b*—open; *c*—superporous

permanently retained in the pores, otherwise the wheel will lose its cutting properties due to "loading".

In Fig. 53, alternative structures of grinding wheels of the same grain size and bond are shown. The denser the structure, the larger the number of grains per unit of surface and the smaller the pores. In an open structure, the number of pores in the wheel is larger and the grains are spaced further apart. In recent years, definite-structure wheels have been introduced, i.e., wheels with a given arrangement and spacing of the pores.

Structure of a wheel is designated in the U.S.S.R. by a number from 1 to 13. Each of these structures is characterized by a definite ratio and relative arrangement of grains, the bond and the pores of the wheel.

Thus, structure 5 for a wheel of hardness CM1 is characterized by the following volume percentages: 52% grains, 9% bond and 39% pores. Structure 6 for a wheel of the same hardness has 50% abrasive grains, 11% bond and 39% pores (by volume).

In Table 9, the percentage by volume of grains in wheels of various structures is shown.

Table 9

Volume Percentage of Grains in Various Structures of Grinding Wheels

Structure No.	Volume of grains, %	Structure No.	Volume of grains, %
1	60	7	48
2	58	8	46
3	56	9	44
4	54	10	42
5	52	11	40
6	50	12	38

Recently, superporous grinding wheels, having structures between 13 and 18, have been developed. The surfaces of such wheels present a spongy appearance. These wheels are considerably lighter than definite-structure wheels. Superporous wheels are less susceptable to loading and, moreover, the large pores permit the currents of air, produced by wheel rotation in grinding, to cool the cutting grains and thereby to improve the cutting properties of the wheel. Ductile materials, such as copper, brass, plastics, leather, etc., can be ground successfully with such wheels.

In selecting a wheel according to its structure, the following rule should be observed: the softer the material to be ground, the higher the structure number, and vice versa.

6-7. WHEEL SHAPES AND MARKING

Shapes of Wheels. Grinding wheels are made in various shapes and sizes. The shape of a wheel is selected to suit the construction of the grinding machine, the mounting devices and grinding conditions.

The size of a grinding wheel is selected according to the size and power of the grinding machine, the size of the articles being ground, the construction and dimensions of the clamping devices and wheel guard. It is, in general, good practice

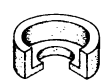
Wheel shape	Description	Shape designation	Wheel shape	Description	Shape designation
	Straight wheel	ПП		Wheel dovetail recessed two sides	ПВП
	Wheel tapered two sides (to 40° face)	2П		Cut-off wheel	Д
	Wheel tapered one side (to 30° face)	4П		Cylinder wheel	1К
	Wheel recessed one side	ПВ		Straight cup wheel	4Ц
	Wheel recessed one side with bevelled face	ПВК		Flaring cup wheel	4К
	Wheel recessed two sides	ПВД		Dish wheel	11,2Т,3Т

Fig. 54. Shapes and designations of grinding wheels

to select the largest size of wheel compatible with these factors, since this improves the conditions of cutting (increases the arc of contact).

The U.S.S.R. standards specify the cross-sectional shape, designation and size of grinding wheels (Fig. 54).

Marking of Wheels. Each grinding wheel has its own characteristics, which are indicated on the wheel by the manufacturer in the form of a conventional marking. The marking includes: the trade mark, the abrasive material, grain size, hardness, structure number, shape of wheel, diameter, width, bore, and the maximum permissible peripheral speed. These data are given by conventional signs in the above sequence on the side of the wheel:

(a) manufacturer's symbol: ЧАЗ (Chelyabinsky Abrazivny Zavod), ЗАЗ (Zaporozhsky Abrazivny Zavod), etc.;

(b) abrasive material: aluminium oxide—Э, white aluminium oxide—ЭБ, monocorundum—М, black silicon carbide—КЧ, and green silicon carbide—КЗ;

(c) grain size number: 12, 16, 20, . . ., 220, 280, 320, М40, М28, etc.;

(d) bond type: vitrified—К, resinoid—Б, rubber—В;

(e) hardness (grade): М1, М2, М3, СМ1, СМ2, С1, С2, СТ1, СТ2, СТ3, Т1, Т2, ВТ1, ВТ2, ЧТ1, ЧТ2;

(f) structure number: 1, 2, 3, 4, etc.;

(g) shape of wheel: straight—ПП; tapered two sides (to 40°)—2П, etc.

Example. A wheel having the marking:

ЧАЗ
ЭБ46 СМ2 К 6
ПП 450 × 63 × 127
35 м/сек

has the following characteristics:

ЧАЗ—manufacturer—Chelyabinsky Abrazivny Zavod;
ЭБ—abrasive material—white aluminium oxide;
46—grain size;
СМ2—hardness of wheel—medium soft, second division;
К—vitrified bond;
6—structure number;
ПП—shape of wheel—straight;
450—diameter, mm;
63—width, mm;
127—bore, mm;
35 м/сек—maximum permissible speed of the wheel.

Grinding wheels of the second quality are marked with the inscription 2С.

Grinding wheels for high-velocity grinding have a red band and are marked 50 м/сек.

6-8. TESTING GRINDING WHEELS

Before a grinding wheel is used in service in a grinder, it must be balanced and tested for soundness. Balancing is carried out in a special device.

All grinding wheels must undergo a test for soundness prior to being installed on the grinding machine, in accordance with the requirements of the U.S.S.R. standards.

Tests are carried out by running the wheel in a special machine at a speed 50 per cent higher than the working speed. The soundness of high-velocity wheels is tested particularly thoroughly. The durations of the tests are given in Table 10.

Table 10

Duration of Soundness Tests for High-velocity Wheels

Diameter of wheel, mm	Below 90	90 to 275	275 to 475	Over 475
Duration of test, min	3	5	7	10

6-9. COATED ABRASIVES

Coated abrasives are abrasive tools made in the form of sheets and belts.

Abrasive sheets are made with a cloth or paper backing. The abrasive grains are held securely on one side of the cloth or paper, in an even layer, by means of special glues. Coated abrasives with a paper backing are called abrasive papers; those with a cloth backing are called abrasive cloths.

The abrasive materials applied to the backing are aluminium oxide, silicon carbide, flint and glass.

In the case of coated abrasives intended for dry sanding (without water cooling), the abrasives are attached by means of hide glue. Water-resistant coated abrasives, intended to operate with water cooling, have the abrasives glued on by means of special lacquers and resins. Such coated abrasives usually have a paper backing, and are available in sheets 310 × 230 mm in size, coated with green silicon carbide grains having a grain size of 80, 100, 120, 150, 180, 230, 280, or 320, or, alternatively, micron powders.

Abrasive belts are usually made from a cloth band glued together into a continuous strip, with an abrasive layer applied to it. In polishing machines, the belt runs over 2 or 3 pulleys of which one is the driving pulley. In operation, the work is pressed against the moving belt. This method also allows workpieces with contoured surfaces to be polished.

CHAPTER

7

The cutting process in grinding

7-1. CHARACTERISTICS OF THE GRINDING PROCESS

Grinding is a superhigh-speed cutting process, which is effected by the entire mass of abrasive grains distributed along the periphery or side of the grinding wheel.

Each individual abrasive grain removes a thin chip from the surface being machined, producing a scratch. The total cutting action is thus the sum of all such scratches produced by the individual grains. The high quality of surface finish characteristic of grinding processes is possible only because the number of such grains present on the tool surface is extremely large, so that the scratches produced are very close together and, indeed, overlap many times.

The cutting edge of any metal cutting tool is formed as the result of special machining and treatment, which provides its geometrical shape and cutting properties. In an abrasive tool, the cutting grains are of random geometrical shape, as well as random distribution, which as a rule forms obtuse cutting angles. This leads to appreciable sliding of the abrasive grains along the metal at the moment preceding penetration and separation of the chip.

Sliding and rubbing, under conditions of the high peripheral speed at which the abrasive grain cuts into the surface being ground, is the reason for the high instantaneous temperature arising at the moment the chip is formed. Owing to the small size of the chip being removed, and the high temperature in the cutting zone, the chip is often heated to the melting temperature and is removed in the form of a solidified drop of metal.

Materials of high hardness can be machined by means of grinding, as for instance hardened steel parts, cemented carbides, hard cast irons, etc. This peculiarity of the grind-

ing process is due to the extremely high hardness and high temperature stability of the abrasive grains in the grinding wheels. The high temperature in the zone of action of the abrasive grain has a beneficial effect in that it increases the plasticity of the material being machined in the cutting zone and thereby facilitates separation of the chip.

7-2. GRINDING CONDITIONS

The grinding conditions in cylindrical grinding include:

(1) peripheral speed of the grinding wheel, called wheel speed;

(2) peripheral speed of the work being ground or rotary feed, called work speed;

(3) rate of longitudinal traverse of wheel or work;

(4) rate of infeed, or depth of cut (grinding).

Peripheral Speed of the Grinding Wheel (Wheel Speed). The length of the path covered by any point on the external surface of a grinding wheel per unit time is called the peripheral speed of the grinding wheel, or simply wheel speed. The wheel speed is expressed in m per sec. In cylindrical grinding practice, wheel speeds of between 20 and 60 m per sec are employed.

The grinding wheel is powered by the electric motor of the wheelhead, usually through a belt drive. The ratio of the pulley diameters on the motor shaft and the wheel spindle determines the rotational speed of the spindle, at which the grinding wheel will have the required peripheral speed.

If the diameter of the grinding wheel is known and if the rotational speed (rpm) of the wheel spindle is to be determined for a given peripheral speed, the following formula is used

$$n_{wh} = \frac{1{,}000 \times 60 v_{wh}}{\pi D} \text{ rpm}$$

where v_{wh} = speed of the wheel, m per sec
n_{wh} = rotational speed of the wheel, rpm
D = diameter of the wheel, mm
π = 3.14 = ratio between the circumference and the diameter.

On the other hand, if the rotational speed (rpm) of the grinding wheel and its diameter are known, then the peripheral speed is

$$v_{wh} = \frac{\pi D n_{wh}}{60 \times 1{,}000} \text{ m per sec}$$

Example. The peripheral speed of a grinding wheel of $D = 500$ mm in diameter is to be determined. Its rotational speed is $n = 1{,}200$ rpm.

Solution.

$$v_{wh} = \frac{\pi D n_{wh}}{60 \times 1{,}000} = \frac{3.14 \times 500 \times 1{,}200}{60 \times 1{,}000} = 31.4 \text{ m per sec}$$

The highest possible peripheral speed is selected for the grinding wheel, since the production capacity increases with the wheel speed and a better surface finish is obtained. The wheel speed is limited by the strength of the wheel and the rigidity of the machine; if the latter is insufficient, high wheel speeds lead to harmful vibrations.

The selection of the wheel speed depends also on whether hand or power feed is employed; the wheel speed must be less for hand feed. The limiting peripheral speeds for various wheels are given in Table 11.

Table 11

Limiting Peripheral Speeds of Grinding Wheels

Wheel shape	Type of bond	Speed, m per sec
ПП	Vitrified	35
ПП	Resinoid	40
ПП	Rubber	35
ПП	Silicate	20
ПВ	Vitrified	35
ПВК	Resinoid	35

Note. According to the U.S.S.R. standard, a peripheral speed of 50 m per sec is permissible for vitrified- and resinoid-bonded high-speed wheels, shape ПП.

Peripheral Speed of the Work Being Ground (Work Speed). The length of the path described by any point on the surface to be ground per minute is known as the

peripheral speed of the work, or simply work speed. It is equal to

$$v_w = \frac{\pi D n_w}{1{,}000} \text{ m per min}$$

where D = diameter of the work, mm
n_w = rotational speed of the work, rpm.

Since both the rotational speed of the work and its peripheral speed are determined per minute, it follows that in contrast to the preceding formula, the multiplier 60 in the denominator is to be omitted.

Example. The peripheral speed of the work is to be determined. It is known that its diameter is $D = 40$ mm and its rotational speed $n_w = 60$ rpm.

Solution. $v_w = \frac{\pi D n_w}{1{,}000} = \frac{3.14 \times 40 \times 60}{1{,}000} = 7.5$ m per min

The work speed is sometimes called the *rotary feed.*

The choice of a suitable work speed depends on the grinding conditions. For rough grinding, a higher work speed can be used than for finish grinding.

Rate of Traverse. This is the distance traversed by the work being ground, in a direction along its axis of rotation, during one revolution of the work. Since this movement occurs relative to the grinding wheel, it is often measured in terms of the wheel width.

It has been found, in practice, most advantageous to operate at the largest possible rates of traverse. However, the maximum rate of traverse cannot exceed 0.9 of the wheel width, since at larger rates an unground helical band will remain on the surface of the work.

The rate of traverse is usually taken as 0.7 to 0.85 H (width of the wheel) for rough grinding, and 0.2 to 0.4 H for finish grinding. In grinding work less than 20 mm in diameter, the rate of traverse is reduced.

Rate of Infeed. The thickness of the metal layer to be ground away in each pass of the wheel is called the infeed or the depth of cut. The thickness of the layer is defined as the distance by which, after the pass, the grinding wheel has approached the axis of rotation of the work being ground. However, it must be noted that, owing to elastic deformation in the feed mechanism and of the work being ground,

the actual thickness of the layer being removed per pass may be somewhat less than the infeed of the grinding wheel or of the work. Thus, when infeed is disengaged a few passes must be made without infeed, i.e., "sparking out".

However, experienced grinders sometimes withdraw the grinding wheel from the work before sparking ceases completely, compensating the deformation of the feed mechanism by a supplementary infeed of 0.01-0.02 mm. Thus they achieve a certain increase in output.

In cylindrical grinding, the rate of infeed for rough grinding is taken from 0.01 to 0.06 mm per full stroke of the table (in both directions). For finish grinding, the rate is 0.0025 to 0.01 mm. For grinding machines in which the infeed is not kinematically linked to table traverse, the infeed is expressed in mm per min.

7-3. THE PROCESS OF CUTTING METAL WITH A GRINDING WHEEL

Chip Formation. The removal of a chip by an abrasive grain is shown diagrammatically in Fig. 55. The tip of the cutting grain is somewhat rounded. Thus, for instance, the abrasive grains of an aluminium oxide wheel with a grain size of 80 have their tips rounded with a radius up to 0.014 mm. The cutting edges of a wheel of grain size 40 are rounded with a radius up to 0.012 mm.

During grinding, the cutting edges of the abrasive grains are dulled. In this respect, the cutting edge of the abrasive grain is similar to the edge of a metallic cutting tool.

Fig. 55*a* corresponds to the moment at which the abrasive grain enters into contact with the surface being ground. No cutting yet occurs and the cutting edge of the grain slides along the surface to be ground, as a result of which the metal under the edge of the abrasive grain is compressed (an elastic-plastic deformation of the metal takes place).

In Fig. 55*b*, the actual process of cutting has still not commenced, and the deformed metal approaches the face of the cutting grain.

At the moment shown in Fig. 55*c*, due to the deformation of the metal and further movement of the cutting edge

on the abrasive grain, its cutting face engages the previously formed projection of metal, displaces it, and shears off the chip.

Thus, the removal of an individual chip by an abrasive grain consists of the sliding of the abrasive grain along the surface being ground, during which time a large quantity of heat is evolved, and of the subsequent shearing of particles of the metal to form the chip.

The shape of the chip formed in grinding is similar to that obtained in milling, only it is very much smaller. However, owing to certain features of the grinding process,

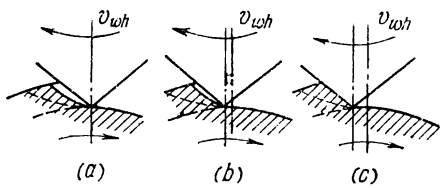


Fig. 55. Cutting a chip in the grinding process

conditions of chip formation often exist which lead to the removal of a chip differing in shape from that characteristic of milling.

An abrasive wheel does not possess a continuous cutting edge along the generatrix, like the milling cutter. For this reason, the abrasive grain, prior to making contact with the metal layer to be removed, often encounters projections or ridges left by the preceding series of grains. In such cases, the obtained chip differs from the ordinary shape.

The heat factor has an even greater influence on the shape of the chip obtained in grinding. As already indicated, sliding of the abrasive grain along the surface to be machined prior to chip formation involves intensive friction and is the reason for the generation of a considerable quantity of heat. This heat is sometimes sufficient to melt the chip. In this case, the latter assume the shape of a solidified drop of metal and does not resemble the usual chip

An analysis of the waste products of grinding shows that there are many such melted chips, particularly when grinding is carried out with a dulled wheel.

The chips removed during grinding get into the pores of the grinding wheel, and on issuing from the grinding zone, they are removed from the wheel surface by the action of the jet of coolant. If the chip has a relatively large cross section (i.e., when the latter exceeds the size of the pores between the grains of the wheel), the chip is pressed into

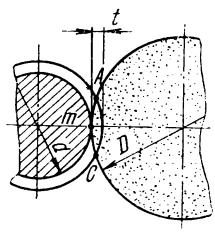


Fig. 56. Length of the contact arc

the pores of the wheel with such force that the action of the coolant is insufficient to remove it. Such conditions during grinding lead to the loading of the wheel and to rejection of the workpiece.

The average thickness of the chip removed by each individual abrasive grain of the wheel also has a great influence on the life and efficiency of the grinding wheel. The average thickness of the chip depends on the length of the arc of contact between the grinding wheel and the work being ground, and on the average thickness of the layer of metal removed in grinding.

The length of the arc of contact between the grinding wheel and the work being ground in cylindrical grinding is shown in Fig. 56, in which the grinding of a shaft of diameter d by means of a grinding wheel of diameter D at a depth of cut t is depicted. The arc AmC will be the arc of contact. The equation required to give the exact value of the length of the arc of contact in cylindrical grinding is complex. However, if it is assumed that the work being

ground is stationary, i.e., that the peripheral speed of the work $v_w = 0$, and the rate of traverse $s = 0$, then the simplified equation will be

$$L_{ext} = \sqrt{\frac{D\,d\,t}{D+d}}$$

where L_{ext} is equal to the length of the arc of contact between the grinding wheel and the work being ground.

The length of the arc of contact has a great influence on the grinding process. As the arc of contact increases, so also does the number of grains participating simultaneously in the cutting process and hence, the quantity of heat evolved. On the other hand, the conditions for the removal of heat by a coolant deteriorate and, therefore, with an increase in length of the arc of contact, the volume of coolant fed to the grinding zone must be increased. An increase in the arc of contact also hinders the removal of the chips and the dust (grit) formed by wear of the abrasive grain and disintegration of the bonding material. This accelerates loading of the wheel.

A peculiarity of the cutting process during grinding is the very small magnitude of the average thickness of the removed layer.

The average thickness of the layer removed by all the abrasive grains within the arc of contact will be the greater, the larger the volume of the metal removed during one revolution of the work, and the lower the peripheral speed of the grinding wheel.

Figure 57 illustrates the method of grinding a shaft with a rate of infeed t and a rate of traverse s per revolution of the work. The cross section of the layer of metal removed from its surface in one revolution of the shaft is shaded in the drawing.

If the speed of the work, which is approximately equal to 1% of the speed of the wheel, is neglected, then the average thickness of the removed layer can be determined from the formula

$$a_{av} = \frac{v_w t}{60 v_{wh}}$$

Mean Thickness of the Chip. To determine the mean thickness of the chip removed by one grain, the average

thickness of the layer of metal removed by all abrasive grains within the arc of contact must be divided by the number of abrasive grains in this zone.

To determine the number of grains, it is sufficient to divide the length of the arc of contact by the distance between two adjacent abrasive grains of the grinding wheel.

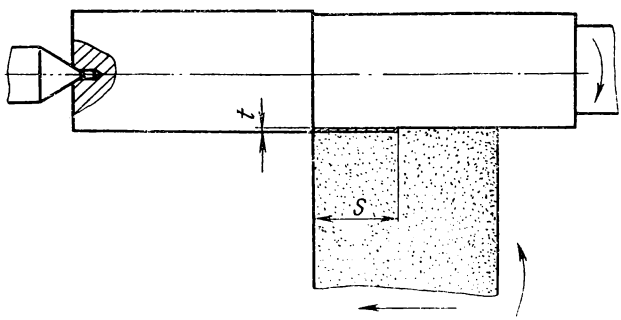


Fig. 57. Grinding a shaft

For each wheel, the distance between the grains depends on the grain size and structure. Thus, for a wheel of grain size 40 and structure number 5, the distance between the grains is 0.369 mm.

Under these conditions, the mean thickness of the chip removed by one grain is

$$a_m = \frac{a_{av}}{z} = \frac{a_{av}}{\frac{L}{l}} = \frac{a_{av}l}{L} = \frac{v_w tl}{60 v_{wh} L} \text{ mm}$$

where z = number of grains within the arc of contact
l = distance between the grains
L = length of the arc of contact.

7-4. FORCES ACTING IN THE GRINDING PROCESS

In grinding three forces act in the zone of contact between the grinding wheel and the work.

The *cutting force*, or *tangential force*, P_z (Fig. 58) acts along the tangent to the circumference of the wheel and

determines the force with which the work being ground acts on the wheel, tending to impede its rotation.

The power ratings of the electric motors driving the grinding wheel and the work are determined by the magnitude of this force.

The *radial force* P_y is the force with which the component is held against the grinding wheel; it is directed towards the axis of the grinding wheel. As the result of the radial

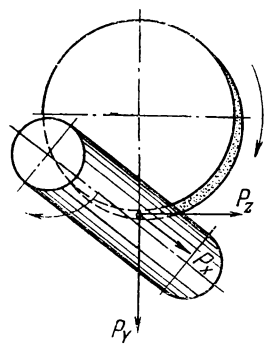


Fig. 58. Forces acting during grinding

force, the cutting grains are pressed against the surface of the work with a pressure sufficient to effect abrasion.

The radial force does not exert any influence on the power requirements of the electric motors. It is taken into consideration in designing the components of the infeed mechanism.

The radial force causes bending of long, thin work during grinding; in magnitude, it is always greater than the cutting force. In grinding with a sharp wheel, $P_y = (1 \text{ to } 2) P_z$; as the wheel becomes dulled, the radial force increases and becomes equal to $(2 \text{ to } 3) P_z$.

The *feed force* P_x is parallel to the traverse. The power of the traverse drive is calculated from the magnitude of this force.

The feed force is considerably less than the cutting force; in grinding with a sharp wheel, it is $(0.1 \text{ to } 0.2) P_z$. As the wheel becomes dulled, the feed force decreases.

Thus, from the cutting force P_z, the radial force P_y and the feed force P_x can be approximately determined.

The cutting force can be determined conventionally in kilograms per square millimetre of cross section of the layer being ground off. This magnitude depends on the properties of the metal being ground and on the depth of grinding (cut).

Universal formulas are available for the determination of the cutting force. Prof. E. Maslov has found that in cylindrical grinding with a wheel, grade Э40СМ1К5, 40 mm in width, the cutting force is

$$P_z = C_p v_w^{0.7} s^{0.7} t^{0.6}$$

where coefficient C_p, which depends on the properties of the material being ground, is:

2.2 for grinding hardened steel;
2.1 for grinding unhardened steel;
2.0 for grinding cast iron.

Example. Let us determine force P_z in grinding a hardened shaft, if $t=0.06$ mm, $s=12$ mm per rev and $v_w=7.5$ m per min.

Solution. $P_z = C_p v_w^{0.7} s^{0.7} t^{0.6} = 2.2 \times 7.5^{0.7} \times 12^{0.7} \times 0.06^{0.6} = 9.4$ kg

7-5. CALCULATION OF THE POWER REQUIRED IN GRINDING

The required power of the motors driving the wheelhead and the headstock of the grinding machine are calculated from the actual cutting force.

The required power of the motor driving the wheelhead is

$$N_{wh} = \frac{1}{102} P_z v_{wh}$$

where $\frac{1}{102}$ is the factor for converting kgf-m per sec into kW.

The required power of the motor of the headstock is

$$N_{hs} = \frac{1}{102} P_z \frac{v_w}{60}$$

Let us determine the required power of the motors of the grinding machine from the data of the preceding example,

If v_{wh} = 25 m per sec and v_w = 7.5 m per min:

$$N_{wd} = \frac{1}{102} P_z v_{wh} = \frac{1}{102} \times 9.4 \times 25 = 2.3 \text{ kW}$$

$$N_{hs} = \frac{1}{102} P_z \frac{v_w}{60} = \frac{1}{102} \times 9.4 \times \frac{7.5}{60} = 0.012 \text{ kW}$$

7-6. WHEEL LIFE

If a grinding wheel works normally, the ground surface will be smooth and the grinding process will proceed steadily without vibrations.

However, as the wheel becomes dulled, facets and small burns will appear on the ground surface. Initially, these

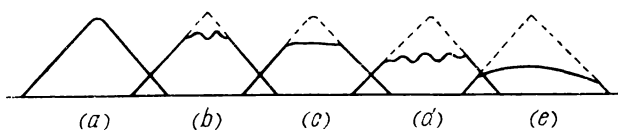


Fig. 59. Dulling of an abrasive grain:
a, *b*, *c*, *d* and *e*—successive stages in dulling

are hardly noticeable, but as the operation continues, they become increasingly evident. Eventually, the wheel will cease to cut the metal and will only slide along the surface of the work, generating intense heat.

The reason why a wheel loses its cutting ability is that the cutting grains on the surface of the wheel become dulled, and the pores between them become loaded with chips and dust.

Figure 59 illustrates the gradual dulling of the grains of aluminium oxide wheel having a grain size 40. In Fig. 59*a*, a cutting grain is shown after a short period of service. The tip of the grain has become rounded and the force required to separate the chip by this grain begins to increase. The grain is still strongly held in the bond, but the strength of the grain itself is insufficient and it cleaves.

In Fig. 59*b*, two new tips have formed on the grain, and its cutting ability has been restored. The cutting force decreases and assumes a normal value.

This property of abrasive grains to restore their cutting ability is called *self-sharpening.*

After some time, the self-sharpened grain again becomes dulled and gradually assumes the shape shown in Fig. 59*c*; simultaneously, the cutting force increases. The grain is destroyed again and begins to cut normally by the newly formed tips.

In Fig. 59*d*, a grain is shown after the second cleaving, and in Fig. 59*e*, after a third dulling. But this time, the height the grain projects above the bonding material is so insignificant that no further splitting takes place. At the same time, however, it is still retained by the bond. As a result, the grain ceases to cut and rubs with a great force against the surface being machined, causing burns and grinding cracks.

The grains which have retained some cutting ability continue to grind; the ground surface will not, however, be as smooth as before, but faceted. Normal operation of the wheel can be restored only if the dulled layer is removed from the wheel surface by some method.

In practice, not all grains are self-sharpening. Some grains can self-sharpen more than twice. Sometimes, in grinding with a soft wheel of grain size 50-40 with large rates of transverse and infeed, self-sharpening occurs continuously, and after one or several cleavages, the residue of an abrasive grain falls out of the bond, exposing new sharp grains.

Grinding with continuous self-sharpening is used in rough grinding or for grinding cemented carbides. In this kind of grinding, the wear of the abrasive tool is extensive, and the surface finish on the work rapidly deteriorates as grinding proceeds.

In practice, grinding with partial self-sharpening is commonly used. In this case, the consumption of abrasive due to falling out of grains is considerably less than that incurred by dressing the wheel. Depending on the type of wheel, as well as on the nature of the work, the ratio of wear of the wheel as a result of falling out of grains to the wear due to dressing is between 1 : 4 and 1 : 6.

Thus, in grinding with a wheel, grade 940CT1K5, the consumption of abrasive between dressings, caused by falling

out of the dull grains (self-sharpening), during finish grinding, is 0.015 mm on the wheel radius, and in each dressing of the wheel a layer, 0.09 mm thick, is removed; hence the ratio will be 0.015 : 0.09 = 1 : 6.

The period of operation of the wheel between two successive dressings is called the *wheel life*. A high wheel life, apart from the economy of abrasive, is advantageous due to the fact that working time is economized, which would otherwise be spent on dressing, as well as on setting up the machine after dressing.

The wheel life can vary within wide limits. For wheels of small diameter it is quite small. However, in cylindrical grinding, in which grinding wheels of large diameters are used, the life is in some cases measured in dozens of minutes or more.

The wheel life depends not only on the wheel size, but also on other factors characterizing the wheel, as well as on the grinding procedure, the material and the size of workpieces being ground. Thus, in the grinding of hardened steel, the wheel life decreases with the diameter of the work being ground.

Wheel life is affected to a greater extent by the peripheral speed of the work and the rate of traverse, and to a lesser extent by the depth of grinding. As any of these parameters increases, the life of the wheel decreases. However, if not only the time between dressings, but also the number of workpieces, made by the machine between successive wheel dressings, is taken as a measure of wheel life, then the expediency of high-velocity grinding becomes evident.

7-7. HEATING OF THE WORK DURING GRINDING

The quantity of heat evolved per kilogram of removed metal in grinding exceeds manyfold the heat evolved on removing the same quantity of metal by milling.

This is associated with the obtuse cutting angles on the majority of abrasive grains, which leads to an increase in frictional forces and hence to the evolution of heat. Cutting with a large number of fine chips, accompanied by the application of impact loads, is the reason for the increase

of internal deformation in the surface layers of the workpieces, which also leads to their heating.

Chip Formation Temperature. Generation of heat during grinding takes place within the arc of contact of the grinding wheel with the work, in the zone of highest temperature. At the moment at which the chip is cut off, the temperature reaches its highest point and is called the *instantaneous temperature.* In the grinding of hardened steel workpieces, the instantaneous temperature often reaches the melting point of the steel.

The abrasive material is characterized by a low heat conductivity, and hence the heat is partly removed by the chip, but mainly by being conducted into the body of the workpiece being ground.

Due to the accumulation of heat, the temperature of the work rises. If grinding is carried out without cooling, the supply of heat to the workpiece will exceed its natural rate of dissipation, and the temperature of the work may rise sharply. Therefore, cylindrical grinding is, as a rule, performed with cooling.

In grinding with cooling (wet grinding), the temperature of the work will rise until the quantity of heat entering the work equals the quantity of heat removed by the coolant. The temperature at which such an equilibrium will be set up is called the *steady temperature.*

In the grinding of precision workpieces, the steady temperature must not differ greatly from the temperature of the ambient air, since the measuring instrument used is verified by a standard having the temperature of the ambient air.

Burns due to Grinding. If excessive heat is evolved in the grinding zone and the coolant is not capable of performing its function sufficiently rapidly, the temperature of the surface layer of the work will soon reach a value at which structural changes begin to take place in the steel. This is often accompanied by the appearance of temper colours on the surface of the work. Such a state of the surface layer of a workpiece is referred to as a *burn.*

Burns should be avoided, since they lower the mechanical properties of the surface layers of workpieces. Depending on the cause, burns may be continuous, when a considerable proportion of the workpiece exhibits temper colours, or local, when individual burns appear on the ground surface.

The appearance of continuous burns on the ground surface after a period considerably shorter than the wheel life can be due to one or several of three reasons:

(1) the grinding speeds and feeds are excessive, as the result of which the mean thickness of the chip removed by one grain of the grinding wheel is too large. Consequently, the pressure of the abrasive grains on the surface being ground will increase sharply, and intense heating of the latter will take place;

(2) the chosen grinding wheel is too hard and is unsuitable for the operating conditions; this also causes excessive pressure of the grinding grains on the surface;

(3) cooling is insufficient.

Local burns on the workpiece surface may be caused by vibration of the machine (as a result of poor balancing of the wheel), due to eccentricity of the wheel (owing to inaccurate locating and mounting of the wheel in the sleeve), and also as a result of inaccurate mounting of the workpiece between the centres or wear of the headstock spindle bearings.

Grinding Cracks. Sometimes fine cracks in the form of a network are formed on the surface during grinding.

The formation of grinding cracks is due to a high instantaneous surface temperature. Being in contact with the wheel, the surface of the work becomes overheated and on issuing from the grinding zone, the work is exposed to a jet of coolant. This sharply changes the volume of metal on the surface. The thermal shock may cause cracking.

Thus, grinding cracks may be formed under conditions similar to those responsible for burns. In practice, the two defects almost always appear together. The depth of penetration of structural changes into the body of the workpiece in the case of burns, and also the depth of grinding cracks are relatively insignificant. If grinding is carefully performed, the wheel can be changed or dressed without delay and, in the next pass, the surface can be reground.

7-8. COOLING AND COOLING FLUIDS

To maintain the temperature of the work being ground within limits close to the temperature of the ambient air, a cooling fluid, or coolant, is usually used in cylindrical

grinding. A constant stream of coolant is delivered to the grinding zone, and it flows over the surface of the workpiece.

Special adjustable nozzles (Fig. 60), mounted at the end of the pipe delivering the coolant, are used to prevent splashing of the liquid. The nozzle is mounted and adjusted in such a way that the stream flows directly into the grinding zone. The width of the nozzle and the size of the supply pipe are selected so that the stream of coolant covers the whole width of the grinding wheel.

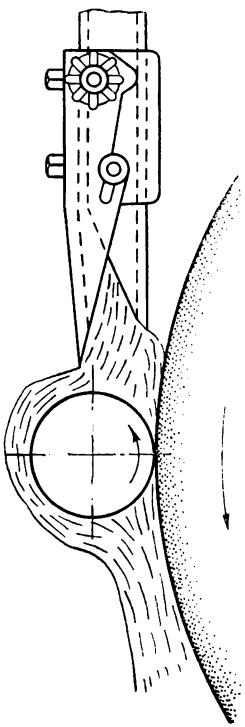


Fig. 60. Device for feeding the coolant

The function of the cooling fluid is not only to remove heat rapidly from the surface layer of the work, but also to wash away grinding waste (chips, broken abrasive grains, dust from the destroyed wheel bond). The cooling action of the fluid minimizes the loss of strength of the grains of the wheel, reduces thermal deformation, and improves the quality and accuracy of grinding.

The cooling fluid must also possess lubricating properties, in order to reduce the friction of the abrasive grains and bonding material against the surface being ground. This enables the cutting force to be decreased and the cutting speed to be increased. However, addition of an excessive quantity of lubricating substance to the cooling liquid may lead to premature loading of the wheel surface.

The cooling fluid also improves the operating conditions, since it eliminates much of the dust formed in grinding.

Lubricating coolants, or cutting fluids, as they are called, must protect the work being ground and the machine itself against corrosion, must be stable enough to retain their original properties for a long time, must not have

toxic or other morbid effects on the personnel, and must not develop unpleasant odours.

Water containing anticorrosive substances (calcined soda, borax, soap, etc.) or emulsions of low concentration are the most common cooling fluids.

In the grinding of steels, a 2-3% aqueous solution of commercial soda with addition of 0.5-0.8% calcined soda is used. For resinoid-bonded wheels, the concentration of the soda solution is lowered to 0.5-1.0%.

Cast iron is usually ground dry, or cooled by an aqueous solution of soda. For the grinding of aluminium alloys, special emulsions are used, while bronze and brass may be cooled with emulsions and mineral oils.

The usual composition of an emulsion is as follows: 1.2% soluble oil or solid paste-type emulsion, 0.5-0.8% calcined soda, and the balance—water. Emulsions of such composition have a milky white colour.

The supply of coolant to the grinding zone must be constant and plentiful. For grinding machines of medium size, a supply of 15 to 20 litres of cooling fluid per minute is recommended. To ensure a good ground finish, the coolant must be free from impurities (dust, abrasive grain grit, etc.), and it is therefore recommended that the cooling system should be periodically drained and thoroughly cleaned.

In shops where a large number of machine tools using cooling fluid of identical composition are concentrated, a central cooling system is used. Such a system consists of a powerful pump, a reservoir of appropriate capacity, and a supply pipeline with branches to the machines and the drainage system.

CHAPTER

8

Typical units of metal-cutting machine tools

8-1. CLASSIFICATION OF METAL-CUTTING MACHINE TOOLS

Metal-cutting machine tools are divided into groups according to the nature of the machining operation they perform. In the Soviet Union, machine tools are classified into nine groups, each with its specific identification code number. Lathes belong to the first group, consisting of machine tools in which work is machined by single-point tools along the internal and external diameters, as well as along the face. In the course of machining, the work rotates and the tool travels along the axis of the work or at an angle to it. The second group comprises drilling and boring machines, the cutting tools of which are drills, core drills, counterbores, reamers and, on boring machines, single-point tools (cutters) as well.

In machines of the milling group, the work is mounted and clamped on the table of the machine and is machined by rotating milling cutters.

Grinding machines form a large and diversified group characterized by the fact that their action is purely abrasive.

Within each group, the machines are in turn subdivided into nine subgroups, with definite types of machines coded by a specific number. The classification of grinding machines into subgroups is shown in Table 12.

In classifying machines in this way, a specific type is usually designated by the model code number, the first digit of which indicates the number of the group, and the second digit, the number of the subgroup.

Further classification, employing code letters of third and fourth numerals, may be added to the first two digits according to the option of the manufacturer. Thus, the numeral 6120 stands for a vertical-spindle knee-type

milling machine having 20 spindle speeds. The numeral 136 stands for a turret lathe; the numeral 6 indicates a spindle bore size of 63 mm.

8-2. GEAR TRAINS OF MACHINE TOOLS

Though metal-cutting machine tools may differ substantially in design, they all have a common purpose: separation of chips or, in other words, the removal of a layer of metal or other material from the surface being machined.

The process of cutting in metal-cutting machine tools is achieved as a result of the primary cutting motion and the feed motion of the operative units.

The *primary cutting motion*, which is associated with the cutting speed, accounts for the major portion of the power requirement of the machine. In lathes, the primary cutting motion is the rotation of the spindle together with the work being machined; in milling machines, it is the rotation of the spindle and the milling cutter; in grinding machines it is the rotation of the spindle on which the abrasive tool is mounted.

Table 12

Classification of Metal-cutting Machine Tools (Grinding Machine Group)

Machines	Group	Subgroup									
		1	2	3	4	5	6	7	8	9
Grinding and microfinishing machines	3	Cylindrical grinders	Internal grinders	Snagging grinders	Specialized grinders	—	Tool and cutter grinders	Surface grinders	Microfinishing machines	Various machines operating by means of abrasive tools

The *feed motion*, whose direction and rate determine the cross section of the chip, may be continuous, as for instance in lathes, milling machines, drill presses and other machines, or intermittent, as in planers, shapers and slotters.

In grinding machines, the feed motion may be either intermittent or continuous.

The primary cutting and feed motions are periodically interrupted to allow the work to be measured, or for the withdrawal and advance of the tool. Motions of parts of the machine tool, during which cutting and chip formation do not occur, are called *auxiliary motions*. The smaller the proportion of auxiliary (handling) motions during the entire working time, the more effectively does the machine work.

The operative units of the machine tool are powered by the drive motor through an intermediate mechanism (speed and feed gearboxes, etc.).

The kinematic linkages existing between the operative units of any metal-cutting machine tool can be established by analyzing its *kinematic*, or *gearing*, *diagram*. The gearing diagram of a machine tool is the schematic representation of the consecutive linkages established between the principal units of the machine, which are referred to by the conventional graphical symbols accepted for kinematic diagrams.

Each worker operating a machine tool must be able to understand its kinematic (gearing) diagram, which is found in the service manual (see Chapter 10).

8-3. SPINDLES AND THEIR SUPPORTS

The spindle is one of the most important components of a machine tool. Therefore, very high standards are set for the accuracy of its manufacture, for the material of which it is made, and also for its assembly.

The dimensions of the spindle are designed so that under the most severe working conditions it should be sufficiently rigid and vibration-resistant.

Spindles are made of chromium-nickel or chromium-nickel-tungsten steels and are heat-treated so that the hardness of the journals and points of tool attachment is within 55-58 R_C.

The journals of the spindle are carefully machined to the tenth or higher class of surface finish, and must be strictly coaxial with the external and internal surfaces for mounting the tool and gears.

Spindle Noses. Many types of spindle noses are employed in machine tools, depending on the cutting tool that is to be clamped in or on the spindle.

The nose of the work spindle in the headstock of a cylindrical grinding machine, shown in Fig. 61*a*, has a thread

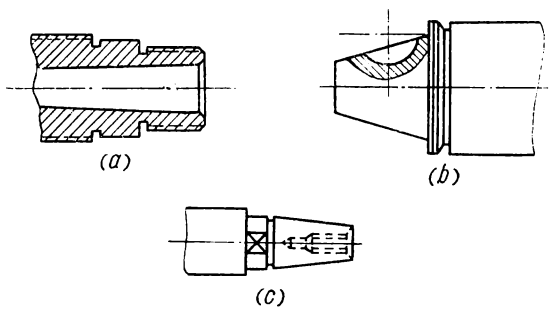


Fig. 61. Noses of grinding machine spindles:
a—with a tapered hole; *b* and *c*—other designs

and a locating shoulder which are strictly coaxial with the bearing journals of the spindle. The hole passing through the spindle ends at the nose in a carefully finished and strictly coaxial tapered hole of standard size, which serves for mounting the headstock centre or a mandrel.

In Fig. 61*b*, the nose of the wheelhead spindle of a cylindrical grinding machine is shown. Fig. 61*c* depicts the spindle nose of an internal grinding machine. In contrast to the work spindle, the wheel spindle is made without a central hole. Grinding wheels are usually mounted on intermediate arbours or wheel sleeves.

Sleeve Bearings. The condition of the bearings that support the spindle is of vital importance for proper operation of the grinding machine.

The bearings must ensure a precise radial and axial position of the spindle with little clearance. Excess clearance leads to a poorer finish of the ground surfaces and to less accuracy of the geometrical features of the workpiece.

At the same time, an insufficient bearing clearance often leads to overheating of the spindle unit, and sometimes to the seizure of the spindle. Normal clearance varies from 0.005 to 0.03 mm, depending on the size and purpose of the grinding machine.

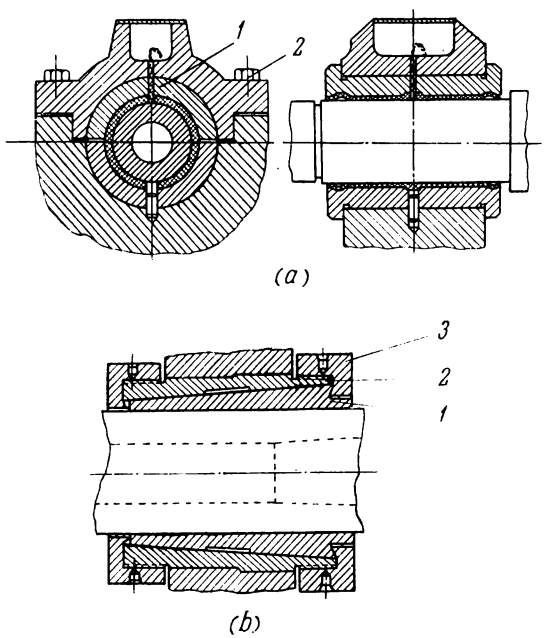


Fig. 62. Sleeve bearings:
a—with radial adjustment of clearance; *b*—with axial adjustment of clearance

In the course of operation, the clearance increases in the bearings, and hence the construction of the bearings is usually such as to enable the clearance to be adjusted. Nonadjustable sleeve bearings are used only with low-speed low-load spindles.

Sleeve bearings can be adjusted in the radial and axial directions.

Figure 62*a* shows a sleeve bearing which can be adjusted radially. The bearing insert consists of two parts, the upper

of which, *1*, may be adjusted by tightening screws *2*. In some constructions, for instance, in the cylindrical grinding machine, model 315, adjustment of the bearing is carried out by oil pressure. The main advantage of split bearings consists in the convenience of assembly and disassembly of the spindle unit.

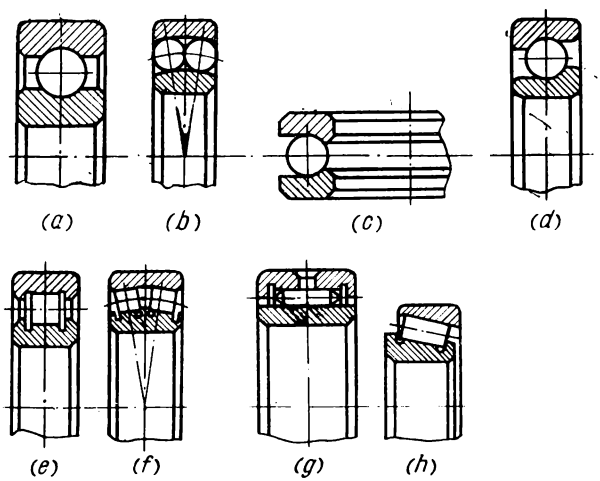


Fig. 63. Antifriction bearings:

a—radial ball bearing; *b*—double-row self-aligning ball bearing; *c*—ball thrust bearing; *d*—angular-contact ball bearing; *e*—cylindrical roller bearing; *f*—double-row self-aligning spherical roller bearing; *g*—needle bearing; *h*—tapered roller bearing

In Fig. 62*b*, a bearing with axial adjustment of the clearance is shown. The bearing insert is of the split type, and the journal of the spindle is cylindrical. Clearance is adjusted by displacement of split insert *1*, which has a tapered external surface exactly fitting the tapered hole of body member *2*. The insert is adjusted and locked by means of nut *3*.

The bearing insert material is selected according to the function of the machine. For high specific loads and relatively slow speeds, antifriction cast iron inserts are used.

At large peripheral speeds bronze is the best material for bearings. The use of bimetallic inserts having a thin

bronze layer not only reduces the cost of the bearing, but improves its quality as well.

Antifriction Bearings. At present, antifriction bearings are widely used for spindle supports. In Fig. 63, various types of such bearings are shown.

Spindles mounted in antifriction bearings have no excess clearance since they can be preloaded when they

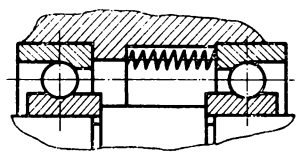


Fig. 64. Preloading ball bearings

are press-fitted on the spindle. Angular-contact ball bearings and tapered roller bearings can be preloaded during assembly of the spindle unit.

Preloading is achieved in radial ball bearings by axial displacement of the outer ring relative to the inner ring, by inserting spacers of various lengths between the rings of a pair of mounted bearings.

Figure 64 shows a method for preloading bearings with springs. This method ensures that the degree of preloading will be maintained, and compensates for wear of the bearing components.

In installing thrust bearings, the latter should be placed as close to one another as possible at one support, to avoid excessive deformation of the spindle owing to temperature changes.

8-4. TYPES OF TRANSMISSION

Transmission Components. The transmission of rotational or other types of motion from one mechanism or unit to another is effected by means of shafts, axles and couplings.

Shafts are used for the transmission of torque to individual units of a machine. The components of the machine (gears, pulleys, couplings) are mounted on shafts and secured by means of keys, splined joints and other methods. For the

mounting of sliding cluster gears and clutch members, four and six-spline shafts are used (Fig. 65).

Shafts which transmit large torques run in antifriction bearings. Low-speed and low-load shafts run in bronze or cast iron sleeve bearings.

For the transmission of rotation to a movable unit, for instance, to a carriage of a lathe, feed rods are used.

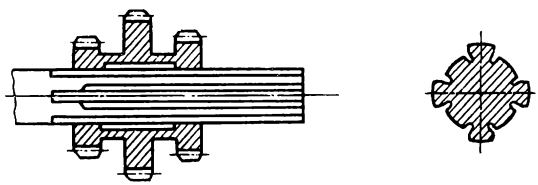


Fig. 65. Four-spline shaft with a sliding triple cluster gear

In large machines these may be ten or more metres long. The choice of a type of steel for the manufacture of a feed rod depends on the magnitude of its maximum load. Steel 40 is used in the U.S.S.R. for medium-loaded shafts. The shaft diameter is determined from the formula

$$d = 10\sqrt[3]{\frac{N}{n}}$$

where N = power transmitted, metric horsepower
n = speed of the shaft, rpm.

Axles, as opposed to shafts, do not transmit torques. Their function is only to support components. An example of an axle is the stud on which intermediate gears are mounted in reversing mechanisms.

Couplings and *clutches* (see Fig. 66) are used to connect shafts to each other, as well as to connect shafts on which various components are mounted. For shafts which are not disconnected during operation, *couplings* are used. Fig. 66*a* shows a coupling, which connects two coaxially mounted shafts.

If the assembly of the shafts is to be carried out without ensuring their strict alignment, then *flexible couplings* are used. In metal-cutting machine tools, shafts are most frequently linked together by *jaw* (Fig. 66*b*) and *toothed*

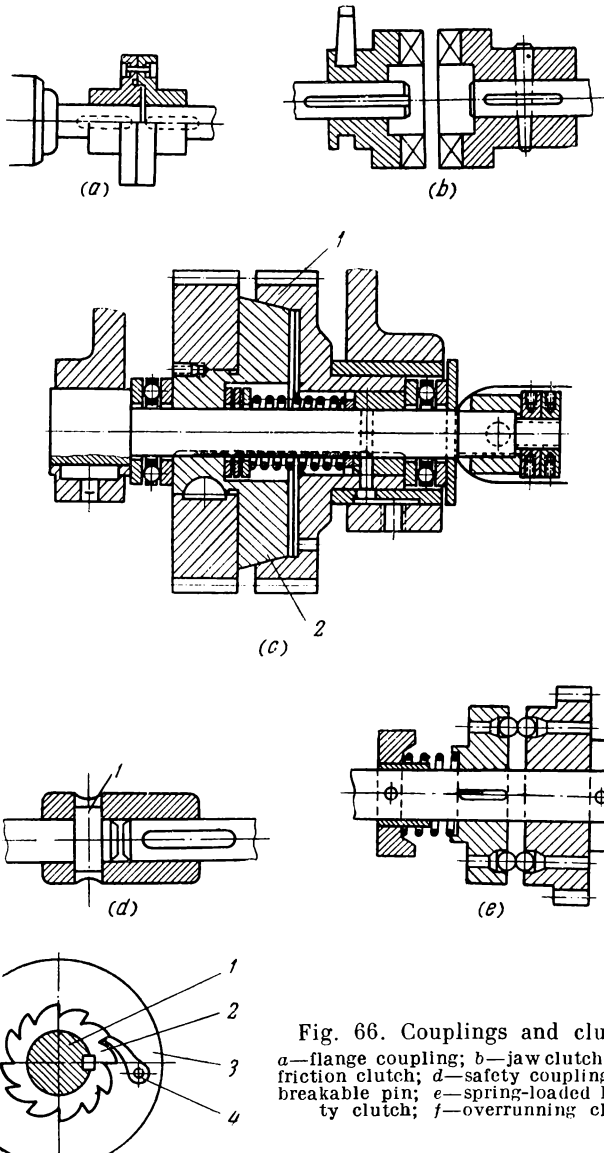


Fig. 66. Couplings and clutches:
a—flange coupling; *b*—jaw clutch; *c*—cone friction clutch; *d*—safety coupling with a breakable pin; *e*—spring-loaded ball safety clutch; *f*—overrunning clutch

clutches, which permit the shafts to be periodically engaged and released. Gears on whose end faces clutch teeth have been milled are often used as clutch members.

The disadvantage of toothed and jaw clutches is that they cannot be engaged while the machine is running. Hence, in cases where this condition is obligatory, *friction clutches* are used (Fig. 66*c*).

To prevent the consequences of a possible overloading of any one mechanism of the machine, a *safety coupling* or *clutch* may be installed on the driving shaft. In Fig. 66*d*, a coupling with a breakable pin is shown. The diameter of pin *1* is designed so that if the upper permissible torque in the transmission is exceeded, the pin will be sheared off.

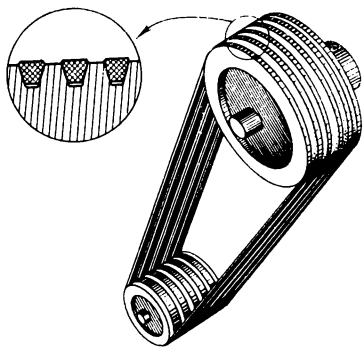
In Fig. 66*e*, a spring-loaded ball safety clutch is shown. Upon an overload this clutch begins to slip, ceasing to transmit the excessive torque. When the load drops again to the permissible value, the clutch is automatically re-engaged.

In rapid traverse mechanisms, *overrunning clutches* are used to provide auxiliary motions (Fig. 66*f*). Shaft *1* of the clutch is rigidly linked to ratchet wheel *2*. Disk *3* rotates shaft *1* at a definite speed through pawl *4* and ratchet wheel *2*.

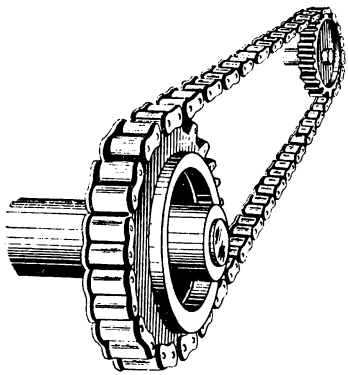
When rapid traverse is engaged, the shaft is driven by a gear (not shown in the drawing) at a speed which exceeds the rotational speed of the disk. Due to the pawl slipping over the ratchet teeth, the lower speed of the disk in no way impedes the accelerated rotation of the shaft if they rotate in the same direction. As soon as the rapid traverse is disengaged, the shaft will no longer be driven by the gear, and the disk will begin to drive the shaft again at a lower speed through the pawl.

Belt Transmissions. Belts (Fig. 67*a*) are suitable for transmission when the distance between the shafts is considerable.

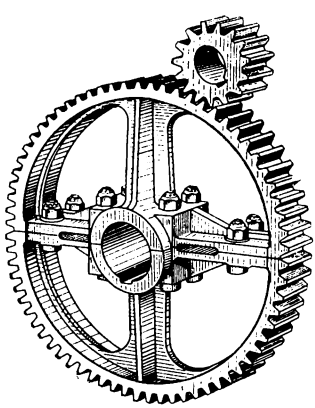
Belt transmission has a number of advantages, among which are the simplicity and low cost of their manufacture, their smooth and silent operation, and their elasticity, which damps variations in the load. The disadvantages of a belt transmission are the increased radial load on the shaft and its supports, a variable transmission ratio and



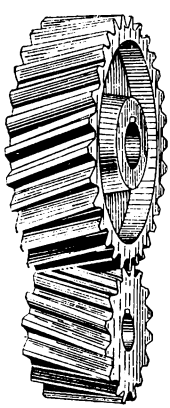
(a)



(b)



(c)



(d)

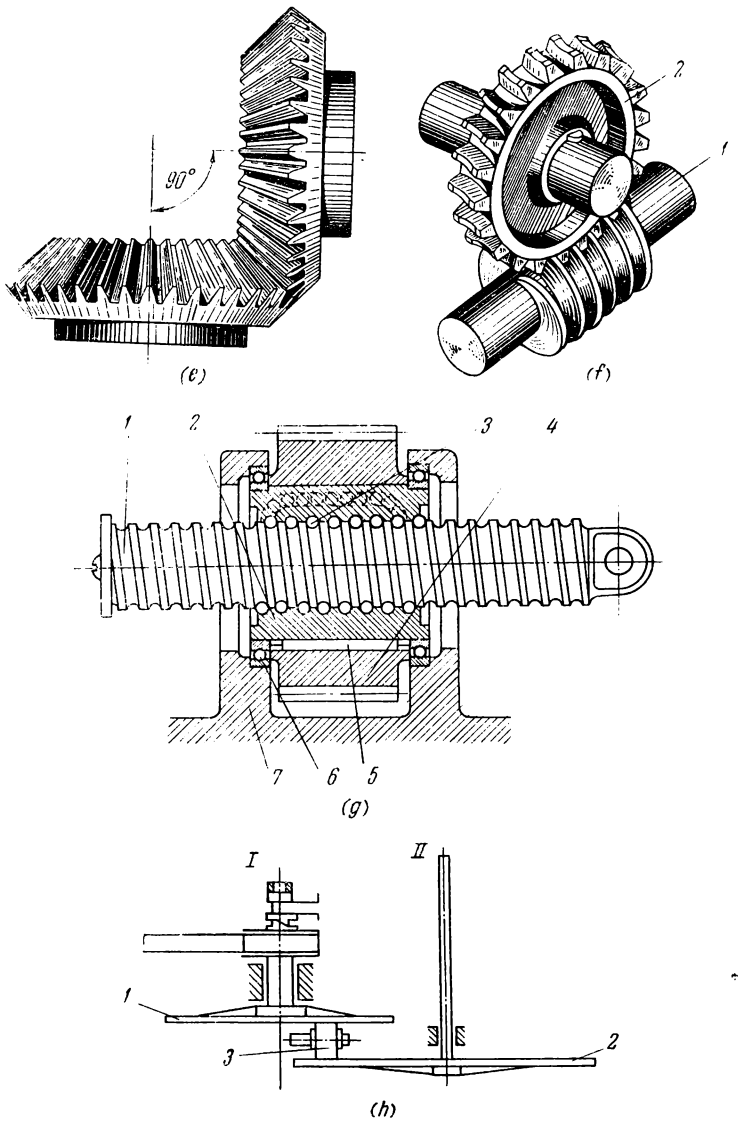


Fig. 67. Types of transmission:
a—belt drive; *b*—chain drive; *c*, *d* and *e*—gearing; *f*—worm gearing; *g*—ball bearing screw mechanism; *h*—friction drive

the possibility of impairing normal operation if oil gets on the belts.

In belt transmission, flat and V-belts are used. In flat-belt transmissions, the pulleys have either a cylindrical or crowned face, and in V-belt transmissions the pulleys have turned grooves of a section which corresponds to that of the belt.

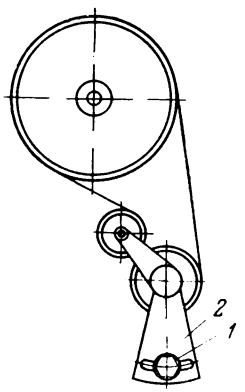


Fig. 68. Tensioning device with an idler pulley

The transmission ratio of a belt drive is

$$i_{bd} = \frac{n_1}{n_2} \quad \frac{D_2}{D_1}$$

where n_1 = speed of the driving shaft, rpm

n_2 = speed of the driven shaft, rpm

D_1 diameter of the driving pulley, mm

D_2 diameter of the driven pulley, mm.

If several different speeds are to be obtained on the driven shaft, stepped pulleys are used. Flat belts may be made of leather, rubberized fabric or canvas.

In production, both endless and jointed belts are used. In transmitting considerable power with V-belts, pulleys with several grooves are used (Fig. 67*a*).

In the course of service, belts gradually stretch and begin to slip. To avoid this, they must be periodically tensioned. One method of tensioning belts consists in mounting the electric motor on a bedplate or slide and adjusting it to increase the distance between the motor and the driven shaft.

A more reliable method consists in tensioning the belts by means of idler pulleys (Fig. 68). In this case, adjustments are made by turning bracket *2* which is fixed by screw *1*. In some tensioning devices the belt tension is maintained by spring action.

Each type of belt is adapted for use at a definite peripheral speed. In machine tool engineering, the following surface speed limits are used for belts: for laced rubberized

fabric belts—25 m/sec, for laced leather belts—40 m/sec, for V-belts—30 m/sec, for endless cotton laminated belts—up to 50 m/sec, for silk belts consisting of a few layers—up to 75 m/sec.

Chain Transmissions. For the same transmitted power, chain transmissions are smaller than belt transmissions. Thus, for the transmission of large torques, chains are more suitable than belts.

For mechanisms requiring accurate, stable transmission ratios, however, a chain transmission is unsuitable, since the transmission ratio of such a system varies within each revolution. Chain transmission is unstable when the loads vary in a wide range.

In metal-cutting machine tools, *roller chains* (Fig. 67*b*) and *silent chains* are most often used. Silent chains operate more quietly and smoothly than roller chains, but they are more complex and more costly to manufacture.

The transmission ratio of chain transmissions is calculated from the formula

$$i_{cd} = \frac{n_1}{n_2} = \frac{z_2}{z_1}$$

where n_1 = speed of the driving shaft, rpm
n_2 = speed of the driven shaft, rpm
z_1 = number of teeth on the driving sprocket
z_2 = number of teeth on the driven sprocket.

Gear Transmissions. Mechanisms with gear transmissions, or gearing, in spite of the complexity of their manufacture and assembly, are widely used in metal-cutting machine tools. This is due to the fact that they ensure an accurate transmission ratio and are compact and reliable in operation. An exception is the group of grinding machines where the application of gearing is limited, since it does not possess the required elasticity and noiselessness at high speeds.

Gears can be spur, helical, or herringbone in type. *Spur gears* have straight teeth (Fig. 67*c*) and may be rigidly mounted on or slide along the shaft.

Helical gears (Fig. 67*d*) are always fixed on the shaft. They operate more smoothly and are used for the transmission of large torques. The disadvantage of helical gearing

is the axial force developed, which must be taken up by the supports.

Herringbone gears also operate smoothly, but they are free from the above-mentioned disadvantage of helical gears.

In addition to these types, *bevel gears* are used for the transmission of rotation between intersecting shafts (Fig. 67*e*). When helical gears are used to drive nonparallel shafts, they are called *spiral* (crossed helical) gears. Such transmissions are not frequently used.

The transmission ratio of a gear drive is determined by the formula

$$i_{gd} = \frac{n_1}{n_2} = \frac{z_2}{z_1}$$

where n_1 = speed of the driving shaft, rpm
n_2 = speed of the driven shaft, rpm
z_1 = number of teeth on the driving gear
z_2 = number of teeth on the driven gear.

Worm Gears. When it is necessary to achieve a large transmission ratio from a single pair of gears, worm gearing is used (Fig. 67*f*). This comprises a worm and a worm wheel. The worms can be single- or multiple-thread.

The transmission ratio of a worm gearing drive can be determined from the formula

$$i_{wd} = \frac{k}{z}$$

where k = number of threads (starts) on the worm
z = number of teeth on the worm wheel.

As a rule, a worm gearing operates with ample lubrication, the oil serving not only as a lubricant, but also for heat removal.

Worms are made of structural or alloy steel, while worm wheels for low-load transmissions (at a worm peripheral speed of less than 3 m/sec) are made of cast iron. For more highly loaded drives, the worm wheels are made of bronze.

Power Screws. Power screws are used mainly for feed mechanisms and positioning movement mechanisms. Mechanisms with power screws are designed for the conversion

of rotational motion to translational motion. These transmissions ensure high accuracy and smooth operation.

Power screw mechanisms are made:

(a) with a rotating screw and a travelling or fixed nut. For instance, in lathes the lead screw rotates and the nut moves forward (together with the carriage);

(b) with a rotating nut and travelling screw, as for instance in the wheelhead elevating mechanism of certain surface grinding machines.

The thread of lead screws is usually trapezoidal; square thread is rarely used.

Lead screws are usually made of structural steel, and nuts for them are made of tin bronze. In less critical cases, antifriction cast iron is used for the nuts.

Power screws are characterized by high friction losses.

Ball bearing screw mechanisms have recently been introduced. In these, sliding friction is substituted by rolling friction.

In Fig. 67*g*, a ball bearing screw mechanism is shown, which is distinguished by its high efficiency. The helical groove of nut *2* accommodates ball bearings *3*. When gear *4*, which is connected with the nut by key *5*, rotates, screw *1* travels under rolling-friction conditions. The angular-contact ball bearings *6*, mounted in housing *7*, also reduce friction losses.

Friction Drives. Mechanisms in which frictional forces are used for the transmission of rotation are called friction drives.

In the spindle drive of machines in which it is desired to maintain a constant cutting speed, a friction mechanism for the stepless variation of the spindle speed is sometimes used. The diagram of one such device is shown in Fig. 67*h*.

Shaft *I* with disk *1* is the driving element, and shaft *II* with disk *2* is the driven element. Between them is small roller *3*. Under the action of a spring, both disks are pressed against the roller, which transmits the rotation of disk *1* to disk *2*. The force pressing the disks against the roller is given by

$$Q = \frac{P}{f}\beta$$

where P = maximum circumferential force acting on disk 2
f = coefficient of friction of the roller on the disk
β = reserve factor, preventing slipping of the drive ($\beta = 1.6$ to 2).

The maximum transmission ratio of the above mechanism, known as the *disk-type infinitely variable frictional speed-changing drive*, is 4, and the maximum transmittable power $N_{max} = 4$ kW.

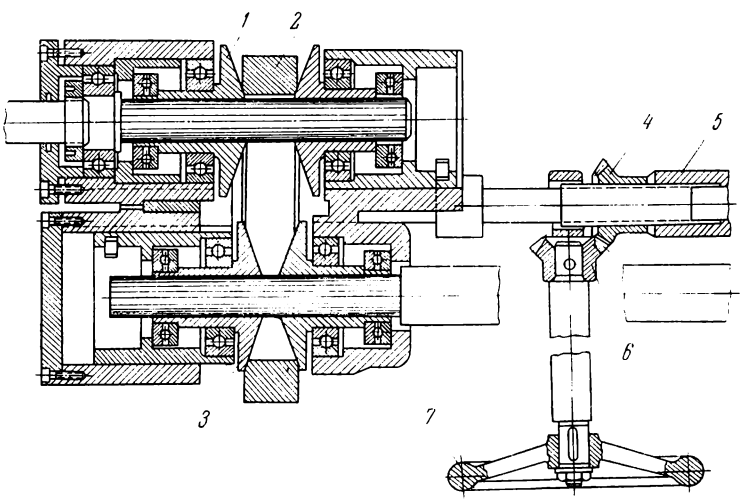


Fig. 69. Friction drive in the headstock of the cylindrical grinder, model 3Д16

The actual transmission ratio of the frictional drive can be determined from the equation

$$i = \frac{n_2}{n_1} = \frac{r_1}{r_2}\varphi$$

where n_1 = speed of the driving shaft, rpm
n_2 = speed of the driven shaft, rpm
r_1 = distance between the roller and the axis of the driving disk
r_2 = distance between the roller and the axis of the driven disk

$\varphi = 0.97$ = factor taking into account slippage of the drive.

Drawbacks of this type are the large size and the intense wear of the roller.

A stepless friction drive of improved construction is shown in Fig. 69. This drive is used in the headstock of the cylindrical grinder, model 3Д16.

A pair of expandable cones *1*, mounted on the driving shaft, is connected by ring *2* with another pair of expandable cones *3* on the driven shaft. Ring *2* has small chamfers (2-2.5 mm) on both faces along the internal diameter, the angle of which corresponds to that of the cones. These chamfers constitute the working surface.

Regulation of the speed of the driven shaft is achieved by handwheel *7* and a pair of bevel gears *4* and *6*. When gear *4*, which is linked to a nut, rotates, screw *5* pushes apart the upper cones and pulls together the lower ones. This reduces the speed of the driven shaft. If the handwheel is turned in the opposite direction, the shaft speed increases. The driven shaft is connected to the headstock spindle.

This drive is compact and reliable, and is therefore used in many types of machine tools.

8-5. HYDRAULIC DRIVES

Purpose and Working Principle. Hydraulic drives are widely used in modern metal-cutting machine tools. They transmit motion from the driving motor to the mechanism of the machine by means of a fluid.

The essential advantages of hydraulic drives are the possibility of stepless variation of speeds within wide limits, the ability of developing considerable pulling forces and torques, even for small sizes of mechanism, the possibility of fully automating the working cycle by simple means, and the long life of the components of a hydraulic drive (pistons, cylinders).

Hydraulic drives are used mainly to produce rectilinear displacements of feed and main drive mechanisms of grinding, planing, broaching and other machines. In some cases they are used for transmitting a rotary motion, as for instance in the thread grinder, model 582, where a hydraulic

drive rotates the workpiece. Hydraulic transmissions are often used for the mechanization of machine controls, for instance, for gear shifting and reversing.

The disadvantages of hydraulic drives include leakage of the working fluid through clearances and seals, failure to operate at very slow speeds (less than 0.1 m per min), and the lack of uniformity of the transmitted motion.

Purified mineral oil is used as the *working fluid* of hydraulic systems. For higher speeds, a less viscous oil is used (Spindle oil 3), and for lower speeds, a more viscous one (Turbine oil JI or Industrial oil 30).

Losses in hydraulic drives consist of mechanical losses (losses due to the friction of moving parts of the hydraulic system), volumetric losses (losses due to leakage of oil through faulty seals and clearances in all units), and hydraulic losses.

Mechanical losses are taken into account by the mechanical efficiency, η_m, the value of which is taken to be the same as in other mechanisms.

Volumetric losses are taken into consideration by the volumetric efficiency, the value of which is

$$\eta_v = \frac{Q_a}{Q_t}$$

where Q_a = actual volume of oil in the working zone of the hydraulic drive

Q_t = theoretical volume of oil for which the pump is designed.

Volumetric efficiency depends on the pressure, temperature and viscosity of the oil, and on the condition of any seals and clearances in the moving elements of the hydraulic system; it varies from 0.9 to 0.985.

Hydraulic losses, caused by the internal friction of the particles of oil, by the friction of the flowing oil against the walls of pipes and other elements of the hydraulic system, by the resistance to oil flow when it encounters sharp changes in direction and cross section in the elbows of pipelines and apertures of the equipment, are evaluated by the hydraulic efficiency, η_h, which ranges from 0.95 to 0.98.

The overall efficiency of the hydraulic drive is thus given by

$$\eta = \eta_m \eta_v \eta_h$$

Apart from a pump and working cylinder, a hydraulic drive comprises speed and pressure regulators, as well

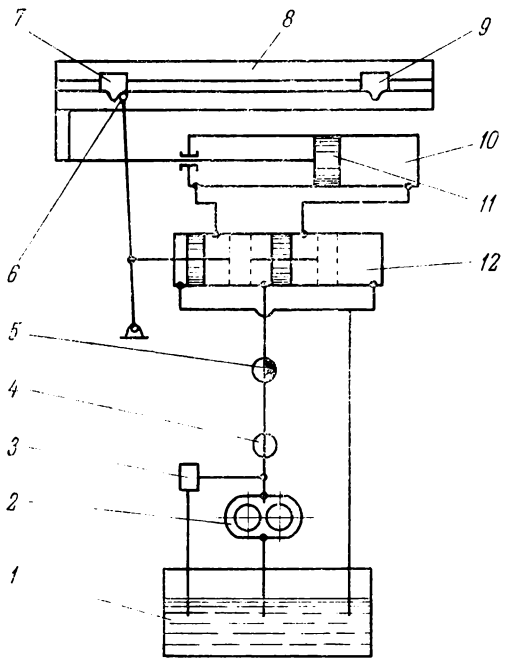


Fig. 70. Diagram of a hydraulic drive imparting reciprocating motion to the table

as distributing devices. Fig. 70 is a schematic drawing of a hydraulic drive producing the reciprocal motion of the table of a cylindrical grinding machine.

Pump *2* takes oil from tank *1* and delivers it through check valve *4* to speed regulator (throttle valve) *5*, and hence to directional valve *12*. When the position of the valve spool is as shown in the drawing, oil enters the left-hand end of working cylinder *10* and pushes piston *11*

together with the table of the machine to the right. At the same time, the oil from the right-hand end of the working cylinder is drained back to the tank.

Dogs *9* and *7*, on the side of table *8*, are set in the required position, the distance between them being the required length of travel of the table. When the table moves to the right, dog *7* runs up against lever *6* and shifts it to the right, upon which the spool of the directional valve takes up the position shown on the drawing by dashed lines. In the new position of the valve spool, oil from the pump will enter the right-hand end of the working cylinder, and the table will begin to move to the left, until dog *9* returns the valve spool to its previous position.

When the machine is stopped for a short period of time for the purpose of measuring or removing a finished workpiece and replacing it by another, the pump is not, as a rule, switched off, and oil flows from the pump through relief valve *3*, draining back into the tank during this period. Sometimes only a part of the oil delivered by the pump is used by the working cylinder while the table is in motion. In such cases, the surplus oil also returns, via the relief valve, to the tank.

Pumps. The purpose of hydraulic pumps (Fig. 71) is to deliver oil into the hydraulic system. In metal-cutting machine tools, pumps of three types are used: spur-gear, vane and radial-piston types.

Spur-gear pumps have a constant output, whereas vane and radial-piston pumps may have either a constant or a variable output.

A *spur-gear pump* (Fig. 71*a*) consists of a pair of spur gears *1* which rotate in housing *2* with extremely small clearances. When the gears revolve in the direction shown by the arrows, the oil entering through passage *II* fills the spaces of the teeth coming out of engagement and is carried by them in the direction of passage *I*. When the teeth engage again, the oil is forced out of the spaces and into passage *I*, which supplies the hydraulic system.

Gear pumps are made for use at low, medium and high pressures. Low-pressure pumps, available in a self-contained unit with a drive motor (type ШДП), are used in cooling systems of metal-cutting machine tools. The same pumps,

for 2 to 5 kgf/cm² pressure, but with no electric motor (type III), are used in the lubricating systems of machine tools.

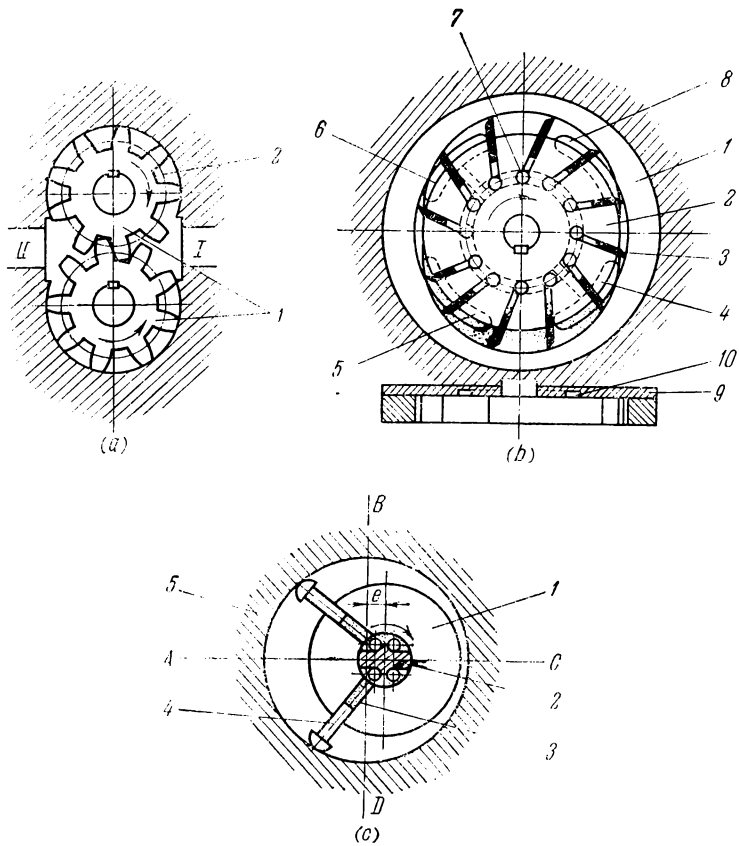


Fig. 71. Hydraulic drive pumps:
a—spur-gear pump; *b*—vane pump; *c*—radial-piston pump

Spur-gear pumps for medium and high pressure (10 to 65 kgf per sq cm) are used for supplying hydraulic systems. The output of such pumps is from 5 to 125 litres per min.

The output of a spur-gear pump with identical gears can be determined to an accuracy within 2% by means of

the formula

$$Q = \frac{\pi S (D - S) bn}{10^6} \text{ litres per min}$$

where D = outside diameter of the gears, mm
S = centre distance between the gears, mm
b = face width of the gears, mm
n = speed of the gears, rpm.

The principle of a double-acting *vane pump* having a constant output is shown in Fig. 71*b*.

The housing of the pump encloses cam ring *1*, having an internal cavity of elongated shape. Inside the cam ring is rotor *2* which runs in bearings mounted in the housing of the pump.

The rotor has 12 slots, 1.8 to 2.5 mm wide, in which vanes *3* slide; the thickness of the latter is 0.01 to 0.02 mm less than the width of the slots, and the width of the vanes is the same amount less than the width of the cam ring. These clearances ensure free movement of the vanes in the slots of the rotor. Under the action of the centrifugal force, the vanes are held constantly against the internal surface of the cam ring.

The cam ring together with the rotor is enclosed by valve plates *9*, in each of which four ports have been milled. Ports *4* and *6* are connected with the suction chamber. Here the space between the blades is filled with oil. After the vanes pass the part of the cam ring profile which is most extended, they are gradually forced into the slots of the rotor and the oil is discharged into the delivery chamber ports *5* and *8*. During one revolution of the rotor, the vanes go through two cycles of suction and delivery, and hence the pump is said to be double-acting.

Annular groove *10*, provided in the valve plates, is connected with delivery ports *5* and *8*. From here, oil enters holes *7* of the rotor so as to set up a pressure under each vane, pressing them against the cam ring. The output of a vane pump is the greater, the more elongated the inside profile of the cam ring, and is directly proportional to the width of this ring.

Pumps used in hydraulic drives are made in eight sizes, having the following specifications:

Delivery, litres per min	5 to 100
Working pressure, kgf per sq cm	up to 65
Motor power, kW	up to 13
Volumetric efficiency η	0.62 to 0.92.

Radial-piston pumps of hydraulic drives enable a pressure up to 200 kgf per sq cm to be developed in a hydraulic system.

A schematic drawing of a radial-piston pump is shown in Fig. 71*c*. Cylinder block (rotor) *1* rotates on fixed pintle *2*, which has two internal passages, separated from each other, along its length. One passage (the lower one in the drawing) is connected to the suction pipe, and the other, to the delivery pipe. The cylinder block has a number of radial holes *3* serving as cylinders for pistons *4*. Rigidly mounted and eccentric with respect to the cylinder block is reaction ring *5*, the internal surface of which contacts the ends of the pistons and is the cause of their reciprocation in the radial direction when the cylinder block rotates. The stroke of each piston is equal to twice the eccentricity *e*.

When the head of the piston moves along the semicircumference *ABC*, it is displaced towards the centre and discharges oil into the upper passage, and from there into the delivery pipe. When the piston head moves along *CDA*, suction of the oil occurs. For each revolution of the rotor, each piston makes one double stroke (in both directions). The number of cylinders can be 5 to 9, and in more powerful pumps, two rows of cylinders are used.

Radial-piston pumps are made in various sizes, and may have outputs of 50 to 200 litres per min at a pressure of 75 to 200 kgf per sq cm.

Working Cylinders. In mechanisms with reciprocal movement, working cylinders are used as hydraulic driving elements.

Working cylinders have a piston with a rod on one (Fig. 72*a*), or both sides (Fig. 72*b*). Cylinders with rods on both sides of the piston operate at the same speed on the forward and return strokes. However, in practice, working cylinders with a piston rod on one side only are often used. In such cylinders, the speed of the piston differs on the forward and return strokes.

To determine the relationship of the piston speeds to the right and to the left, the following notation is introduced:

F = cross-sectional area of the cylinder
F_r = cross-sectional area of the rod
$F_0 = F - F_r$ = effective cross-sectional area of the left-hand end of the cylinder
v_1 = velocity of the piston to the right
v_2 = velocity of the piston to the left
Q = oil delivery.

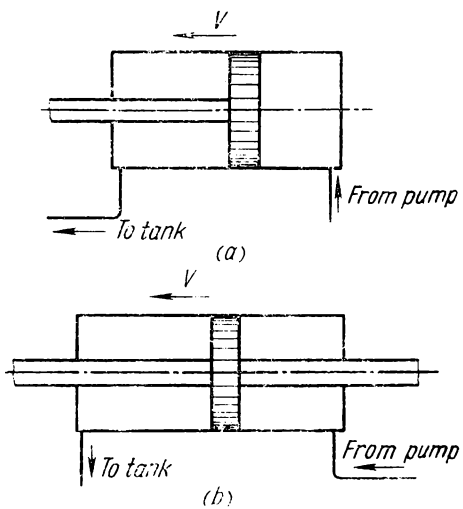


Fig. 72. Hydraulic cylinders:
a—with a rod on one side; b—with rods on both sides

From the equation of equal delivery to either end of the cylinder

$$Q = F_0 v_1 = F v_2 = (F - F_r) v_1$$

whence

$$\frac{v_2}{v_1} = \frac{F - F_r}{F} = 1 - \frac{F_r}{F}$$

Usually the ratio between the rod and cylinder diameters is 0.25 to 0.4.

Example. Determine the ratio of piston speeds to the right and to the left, if the rod diameter is 0.4 of the cylinder diameter, i.e., $d/D = 0.4$.

Solution.

$$\frac{v_2}{v_1}=1-\frac{F_r}{F}$$

$$\frac{F_r}{F}=\frac{\pi d^2}{\pi D^2}=\frac{d^2}{D^2}=0.4^2=0.16$$

whence

$$\frac{v_2}{v_1}=1-0.16=0.84$$

Hence,

$$v_1=\frac{v_2}{0.84}=1.2v_2$$

Speed and Directional Control in a Hydraulic Drive. In the operation of a machine tool, the speed of movement of the working mechanisms must be varied. This may be achieved by regulating the quantity of oil entering the working cylinders of the hydraulic drive by means of a flow-control, or a *throttle valve.* A slit-type throttle valve (Fig. 73) is most frequently used.

By turning throttle member *1*, the size of the slit for the flow of oil from passage *2* to passage *3* is changed. This

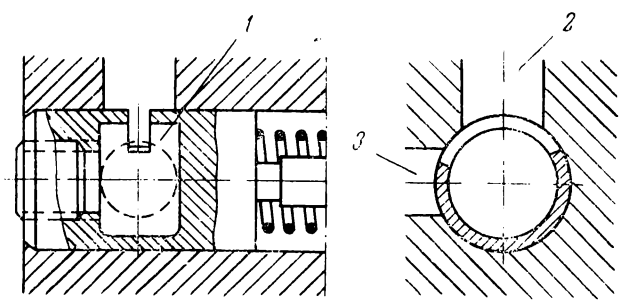


Fig. 73. Slit-type throttle valve

change affects the hydraulic resistance to oil flow. The smaller the slit, the greater the hydraulic resistance and the smaller the quantity of oil admitted, and vice versa.

Regulation by a throttle valve ensures a stepless change in speed of the working mechanisms within wide limits; thus, the rate of traverse of internal grinding machine,

model 3250, may be varied from 250 to 8,000 mm per min. Throttle valves can be mounted either in the pipeline through which oil is delivered to the working cylinder (metering-in control), or at the exit from the cylinder (metering-out control). The latter is most frequently employed since it ensures more uniform travel of the piston.

In hydraulic drives of metal-cutting machine tools, constant-output pumps are usually used. However, since

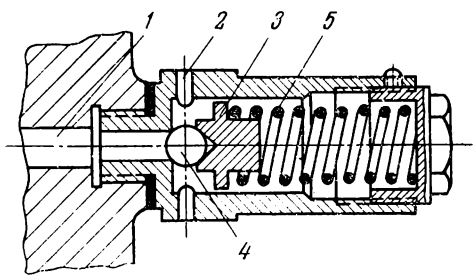


Fig. 74. Ball-type relief valve

oil consumption may vary within considerable limits, surplus oil sometimes accumulates in the hydraulic system of the machine. To avoid pressure jumps in the hydraulic system, the surplus oil is drained back to the tank, by-passing the working cylinders through the *relief valves.*

In Fig. 74, the cross section of a ball-type relief valve is shown. Passage *1* is connected to the piping of the hydraulic system. Spring *5* exerts a pressure on member *3*, which by means of ball *4* closes passage *1*. Spring *2* is selected so that at a pressure in the hydraulic system exceeding the normal, the ball is pushed back, compressing the spring and opens the exit for the oil from passage *1* to passages *2*, leading to the tank. Oil overflow continues until the normal pressure is restored in the system.

Directional-control valves are used to direct the flow of oil to the working cylinders of the hydraulic drive and for its drainage to the tank after the operational cycle.

Directional valves may be of the rotary or spool type. In Fig. 75 the mechanism of a rotary four-way valve is shown. Housing *12* has four ports, connected respectively

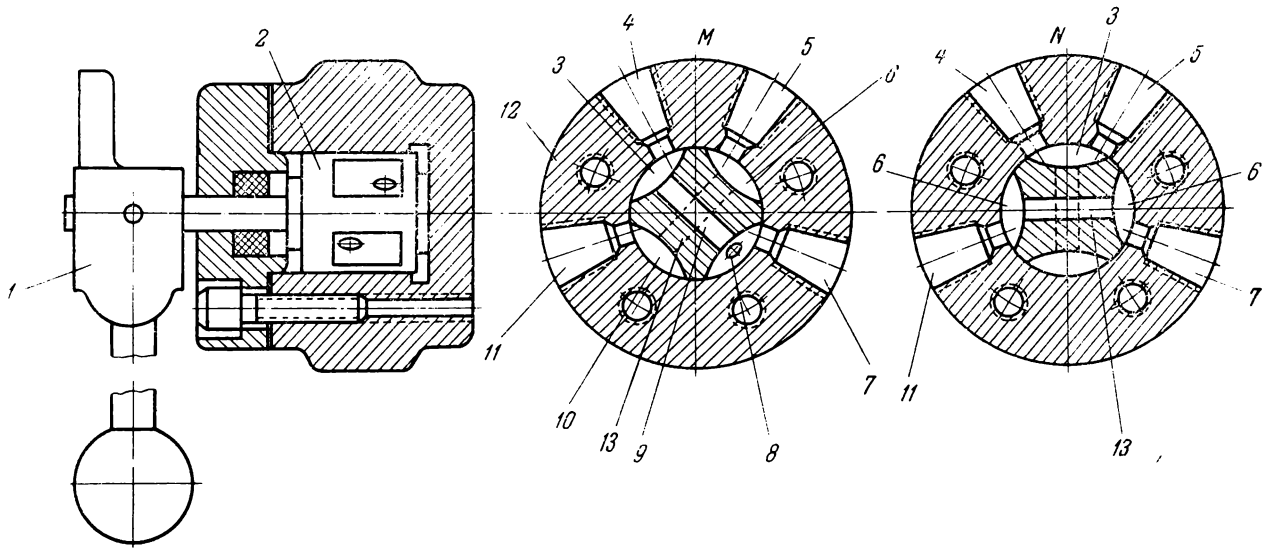


Fig. 75. Rotary four-way valve

to the pump, tank and to each end of the working cylinder. The other ends of these ports are connected to the respective chamber on the external surface of valve member *2*.

When handle *1* is in position *M*, oil from the pump enters port *4*. From there, the oil flows through chamber *3* and hole *9* of the valve member, into chamber *8*. Finally it passes through port *7* of the housing to the right-hand end of the cylinder. At the same time, oil flows from the left-hand end of the cylinder to port *5*, chamber *6*, hole *13* of the valve member, into chamber *10*. Then it passes through port *11* and drains to the tank.

When the handle of the valve is in position *N*, oil is delivered by the pump through port *4*, chamber *3* and port *5*, into the left-hand end of the cylinder. At the same time, oil flows from the right-hand end through port *7*, chamber *6* and hole *13*, into port *11* and on to the tank. Handle *1* of the directional-control valve can be actuated either by hand or mechanically.

Directional control of oil flow with the aid of a spool-type valve is shown in Fig. 70. Constructions of valves are standardized in the U.S.S.R. Thus, Г-72 valves with hydraulic control (pilot-operated) are available in seven different sizes.

8-6. ELECTRICAL DRIVES

As a rule, each metal-cutting machine tool is powered by an individual electrical drive consisting of one or several electric motors.

In many grinding machines, the wheel spindle is driven by an electric motor of the $Ш_2$ or $Ш_5$ type which is mounted on the wheelhead housing. Rotation is transmitted to the wheel spindle by V-belts.

Frequently, flange-mounted electric motors of the $Ф_2$ or $В_3$ type are used. They are directly connected with the driving shaft of the mechanism, and the motor shaft may be positioned either horizontally or vertically.

Built-in electric motors, the rotor of which is an integral part of the spindle, have also found wide application; for instance, motorized spindle heads of internal grinding machines.

In metal-cutting machine tools, three-phase (squirrel-cage induction) motors are mainly used. These may be of open or closed (protected) design. Usually closed electric motors are used, in which the revolving and current-conducting components are reliably protected.

The functioning of the induction motor is described in the following chapter.

CHAPTER

9

Electrical equipment of metal-cutting machine tools

9-1. DIRECT CURRENT

If two terminals, of which in the first there is an excess, and in the second, a deficiency of electrons, are connected by a copper conductor, the excess electrons will instantly transfer from the first terminal to the second. Such a movement of electrons along a conductor is called an *electric current.*

If the quantity of electricity passing through a conductor per unit time, and the direction of its movement are constant, then such a current is called a *direct current.* The magnitude of a direct current is determined by the quantity of electricity passing through the cross section of the conductor in one second

$$I = \frac{Q}{t}$$

where I = magnitude of the current
Q = quantity of electricity
t = time.

The unit of current is one ampere (A). If the magnitude of the current is referred to a unit cross-sectional area of the conductor, the current density is obtained; this is measured in A per sq mm.

The passage of electrons along a conductor is impeded by the atoms of the latter. This generates heat in the conductor. The magnitude of this resistance to current flow depends on the material of the conductor, its cross-sectional area and length. The adopted unit of resistance is 1 ohm (Ω).

The resistance, in ohms, of a conductor of 1 m length and 1 sq mm cross section is called the *specific resistance* of the conductor material (ϱ). Thus, the resistance of a con-

ductor is

$$R = \frac{\varrho l}{s}\ \Omega$$

where ϱ = specific resistance, ohms
l = length of the conductor, m
s = cross-sectional area of the conductor, sq mm.

Frequently a conductor is described in terms of its conductance of electric current. The *conductance of a conductor* is given by

$$q = \frac{1}{R}$$

i.e., the conductance is inversely proportional to the resistance of the conductor.

The source of an electric current is the difference in the number of electrons at each terminal, or, in other words, a *difference in the electric potentials* thereof. The force which sets up and constantly maintains the difference of potentials is called the *electromotive force* (emf).

The difference of potentials, or voltage, in any portion of a circuit, the resistance of that portion and the current flowing in it are related to each other by a formula expressing Ohm's law

$$I = \frac{E}{R}$$

where I = current, A
E = voltage, V
R = resistance, Ω.

Separate conductors of an electric circuit can be connected to each other in series, in parallel, or series-parallel arrangement.

A *series connection* is one in which the end of the first conductor is connected to the beginning of the second, the end of the second to the beginning of the third, etc.

A *parallel connection* is one in which all the conductors are connected between the same two terminal points.

In a *series-parallel connection*, some of the conductors in an electric circuit are connected in series, and some in parallel.

The work performed by an electric current is determined by the formula

$$W = EIt$$

or

$$W = I^2Rt$$

The unit of work is one joule (J), which is the work done by a current of one A under a voltage of one V during one sec.

The power of a current is determined from the formula

$$P = \frac{W}{t} = \frac{EIt}{t} = EI$$

The unit of power is one watt (W). Larger units of power are one kilowatt = 1,000 W and one megawatt = one million W.

9-2. ALTERNATING CURRENT

Electric motors for metal-cutting machine tools are usually supplied by alternating current. When the current is alternating, its magnitude and direction of movement change continuously. The nature of this change is determined by the type of generator which produces the alternating current.

In one revolution of the rotor of a two-pole alternating current generator, the magnitude of the current experiences the following changes: at the initial moment of motion of the rotor, called the beginning of the phase, the current is equal to 0; at 90° it attains its maximum value; at 180° (i.e., after a half-revolution) the current is again zero; at 270°, the current again attains its maximum value, but it flows in the opposite direction; at 360°, the current falls to zero. Thereafter the cycle is repeated.

The number of such cycles per second is called the frequency of the alternating current, and the duration of the cycle is called the *period of the alternating current.*

If three such sources of alternating current of identical frequency are combined, but with the beginning of the phases displaced by 120°, a *three-phase alternating electric current* is obtained.

The method of combining the phase windings of a generator, shown in Fig. 76*a*, is called a *star connection.* In this arrangement, the ends of all the windings are connected to each other, and the beginning of each winding is connected to the corresponding line wire. With this system, the current in the phases is equal to the line current, and the line and phase voltages have the relationship

$$E_l = E_{ph}\sqrt{3} = 1.732E_{ph}$$

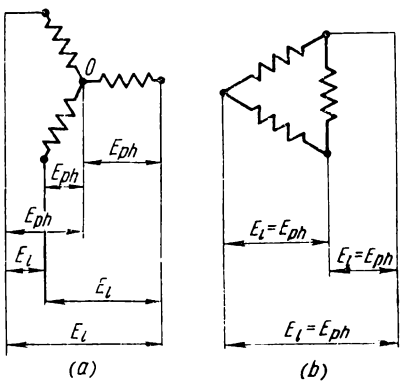


Fig. 76. Connecting the phase windings of a generator: *a*—star connection; *b*—delta connection

If the ends of the phases are connected in a *triangle* (delta connection) (Fig. 76*b*), i.e., if the phase windings are connected in series, then

$$E_l = E_{ph}; \quad I_l = \sqrt{3}\, I_{ph}$$

The power of a three-phase current in both methods of phase connection is

$$P = 3E_{ph}I_{ph}\cos\varphi$$

or

$$P = \sqrt{3}\, E_l I_l \cos\varphi$$

The value cos φ is called the *power factor* which depends on the nature of the resistance in the circuit. The higher the value of cos φ, the more favourable will be the functioning of the electric circuit.

Transformers. Alternating current produced by a generator has a voltage of 6,000 to 15,000 V, and electric motors are made to operate at a voltage of not more than 500 V. Thus, special devices are used to transform a high voltage to a low one (and vice versa); these are known as transformers.

The principle of a transformer is as follows. If a current at E_1 volts is supplied to a coil of w_1 turns, then a current at E_2 volts will be excited in another coil of w_2 turns wound on the same iron core as the first, and

$$\frac{E_1}{E_2} = \frac{w_1}{w_2} = K$$

where K is the transformation ratio.

To supply an electric motor with a voltage of 220 V from a 6,000 V generator, the transformation ratio must be

$$K = \frac{6{,}000}{220} \approx 27$$

9-3. INDUCTION MOTORS

Squirrel-cage induction motors, used as drives for metal-cutting machine tools, consist of a stator and a rotor. The stator has a three-phase winding supplied by a three-phase current. On switching the stator windings into the circuit of the three-phase alternating current, a rotating magnetic field is set up, which induces current in the short-circuited (squirrel-cage) rotor. The rotor current, by interacting with the rotating magnetic field of the stator, sets up a torque, under the action of which the rotor begins to revolve in the same direction as the magnetic field of the stator.

The speed of rotation of the rotor is always slightly less than that of the magnetic field of the stator, and therefore such motors are also called *asynchronous*.

Three-phase electric motors of the standard series, produced by the Soviet electrical industry, are identified by a code which indicates the frame material, the degree of protection, the size and the number of poles. Thus, the symbol AOJI 62/6 denotes an electric motor with an alu-

minium frame, totally enclosed, size 62 and with 6 poles. A similar motor with a cast iron frame is denoted by AO 62/6.

Induction motors are made for voltages of 127-220, 220-380 and 500 V. The actual working voltage of an electric motor depends on how it is connected to the circuit. Connecting an electric motor into the circuit in a delta arrangement gives a lower working voltage (127-220 V), and, in a star arrangement, a higher one (220-380 V).

Electric motors used in machine tools run at one of the following speeds: 3,000, 1,500, 1,000, 750, 600, or 500 rpm. Sometimes two-, three- or four- speed electric motors are used.

The operation of a metal-cutting machine tool may involve considerable variation in load, but the rotational speed of the spindle must remain constant. This has proved possible owing to the ability of squirrel-cage induction motors to change their rotational speed only slightly when the load varies. Temporary overloading of an electric motor by a factor of 2 to 2.5 changes its speed only by 10 to 15%. Upon further increase in load, the speed of the motor drops suddenly and it stops.

When a machine tool is started, the drive motor must overcome the additional resistance of the forces of inertia of the components that must be set in motion. Thus, the ability of squirrel-cage induction motors to develop, at the time of starting, a torque exceeding the normal value is also an advantage. In some cases the ratio of the starting torque to the nominal torque is as high as 1.7.

An undesirable feature of the induction motor is the high starting current; it is some six times greater than for established motion. For this reason, powerful machines must be started with minimum load, and the main mechanisms must be engaged when the drive motor has reached full speed.

The maximum starting current does not exert a harmful influence on the motor itself, since it acts only for a fraction of a second; however, it may affect other machines running in the shop.

Reversal of an induction motor (changing the direction of rotation) is easily brought about by changing over any two external leads of the phase windings.

However, such a method is used only in cases when the number of reversals per hour is not very high (20 to 30).

9-4. STARTING DEVICES

Electric motors and other electric mechanisms of machine tools are switched on and controlled by means of knife switches, push-button starters and other control devices.

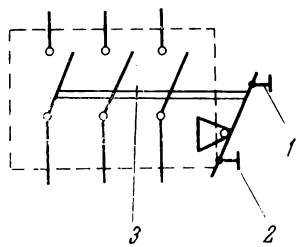


Fig. 77. Diagram of a three-pole starter

A *knife switch* is designed to switch an electric motor or a group of motors directly into a circuit, in cases when the power supply is taken from a separate cabinet. All components of a knife switch through which current flows are enclosed, and only the insulated handle projects from the housing.

The *three-pole push-button starters*, type KA-73A, are also designed for directly switching an electric motor across the mains. The principle of a three-pole starter is shown in Fig. 77. When button *1* is pressed, lever *3* is shifted, closing all the three contacts simultaneously. Button *2* is used to switch off the motor.

Rotary packet-type switches are used for switching motors on, reversing them, and switching them off. A diagram of a rotary switch is shown in Fig. 78. The handle of the switch can be turned through 360° and can be fixed in three positions at 120° intervals. In the first position of the handle (Fig. 78*a*), all three phases of the motor are disconnected from the circuit (the motor is switched off.) When the handle is set to the second position (Fig. 78*b*), the motor is cut in and current is supplied from the phase lines in the sequence L_3—L_1—L_2.

To reverse the motor, the switch handle is turned to the third position (Fig. 78*c*). The current is then supplied in the order: L_3—L_2—L_1. Since phases L_1 and L_2 have changed places, the motor will rotate in the opposite direction.

A rotary switch is used only when the motor is started a limited number of times per hour.

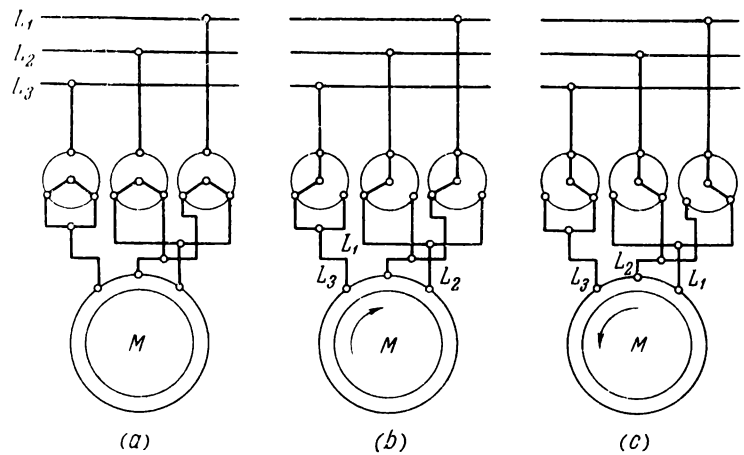


Fig. 78. Diagram of a rotary packet-type switch: *a*—off position; *b*—on position; *c*—reversing connection

Push-button stations (Fig. 79*a*) are used on practically all machine tools. They are designed for starting, reversing, and for switching off motors.

Fig. 79*b* shows the design of a push-button element. By pressing button *1*, rod *5* is depressed, and contact bridge *3* at the end of the rod makes contact with fixed contact *4*. The buttons are interlocked, and when any button is depressed, the previously depressed button will return to its initial position by the action of spring *2*.

The push-button station is very compact and can be accommodated anywhere on the machine. In large machines, pendent push-button stations are also used.

Contactor control. The devices discussed above for starting an electric motor are characterized by the fact that they are switched directly into the controlled circuit and are called the manual control devices of electric motors. In met-

al-cutting machine tools, intermediate control contactor devices for electric motors are generally used. Such devices are not switched into the power circuit but into the intermediate control circuit which is insulated from the power circuit.

Figure 80 is a diagram of the contactor control of an electric motor. The solenoid S consists of a coil with a large

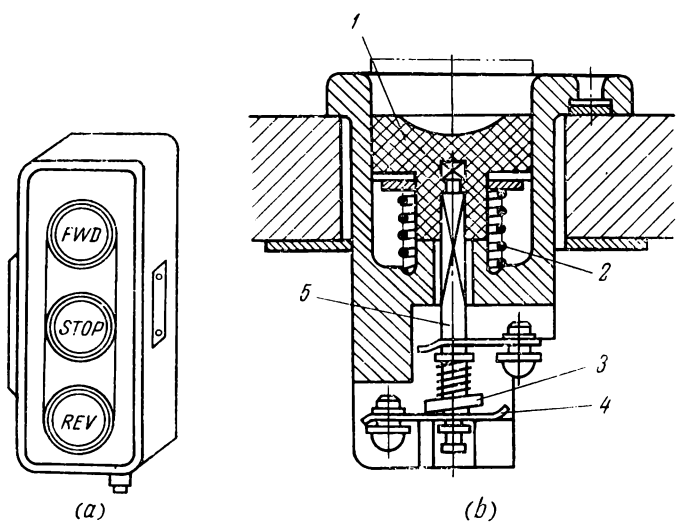


Fig. 79. Push-button station:
a—general view; *b*—mechanism of a push-button element

number of turns of thin wire. On depressing the start button, a current will flow through the solenoid coil. This sets up a magnetic field which draws in the core of the coil and closes switch A, thereby switching on the electric motor.

On depressing the stop button, the current supply to the solenoid is discontinued, the core is returned to its original position by its spring, the switch is opened and the electric motor stops.

Magnetic starters consist of a set of contactor devices joined together, and are designed to start, reverse and stop an electric motor.

Magnetic starters exclude the possibility of accidental starting of an electric motor, since on discontinuing the current supply to the circuit, the coil core disconnects the switch by the action of the spring. The motor may then only be restarted by depressing the start button again.

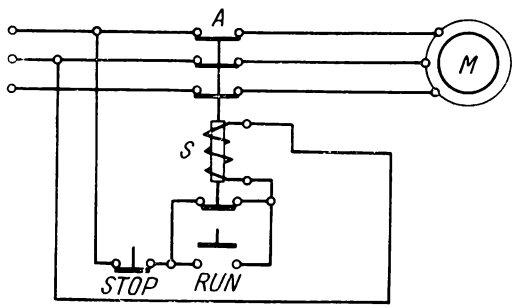


Fig. 80. Diagram of a contactor control

Magnetic starters permit a considerably greater number of starts per hour (120 to 500) than manual starting devices (20 to 30).

9-5. PROTECTIVE DEVICES

Fuses are used to prevent overloading of a machine tool, which may lead to breakage of its units or components, or to the burning out of the stator winding of the drive motor. When the current exceeds the maximum permissible value, the current-conducting wire of the fuse melts and breaks the circuit supplying the electric motor.

The disadvantage of this method of protection is the lack of automatic restoration of the interrupted electric circuit. For this reason use is made of thermal relays, which disconnect the electric motor when it is overloaded, and automatically connect it again when the excess load is removed.

9-6. ELECTRICAL SAFETY MEASURES

The responsibility of ensuring a good state of repair of the electrical equipment and constantly servicing it lies with the electricians on duty. Workers operating a ma-

chine tool are not allowed to eliminate defects in the electrical equipment of the machine. Nevertheless, the worker must know the elementary rules of electrical safety in machine operation, namely:

(1) all current-conducting and power supply elements must be insulated and enclosed;

(2) defects in the electrical control equipment of a machine must be eliminated only by an electrician;

(3) beds of machine tools and frames of motors must be reliably earthed;

(4) when operating portable electrical tools, use receptacles and plugs with an earthed pin;

(5) when electric sparks appear on machine parts, or when a shock is felt on touching the machine, work must be discontinued and measures taken by the electrician to repair the wiring of the machine.

CHAPTER
10

Cylindrical grinding machines

10-1. TYPES AND PURPOSES OF CYLINDRICAL GRINDING MACHINES

Work is ground in grinding machines to obtain a high dimensional accuracy and a good surface finish. Grinding is also the chief method of finish machining workpieces that have been heat-treated to high hardness.

Cylindrical grinders are designed to grind external cylindrical and tapered surfaces and faces. Also available are *universal cylindrical grinders*, as for instance Soviet model 312M (Fig. 81) which, apart from grinding external surfaces, is also adapted to grinding cylindrical and tapered holes.

In other cylindrical grinders, provision is made for grinding holes by means of special attachments. However, in practice, internal grinding is carried out mainly by *internal grinders*. In these machines, the work being ground rotates so as to effect a circular feed.

When a hole is to be ground in a workpiece whose large size precludes its rotation, the circular feed is effected by the grinding spindle. Revolving around its own axis, the spindle together with its axis describes a supplementary, so-called planetary, revolution about the axis of the surface being ground. Machines working by such a method are called *planetary grinders*.

For mass and large-batch production, *centreless cylindrical grinders* are used for the external grinding of cylindrical, tapered and formed work. Less frequently, such machines are used for internal grinding.

In mass production, the most important place is currently occupied by grinding machines with a semiautomatic or automatic cycle of operation. Semiautomatic machines

differ from automatic ones in that the removal of the ground workpiece and the loading of the next one are effected by hand, all other operations being carried out automatically.

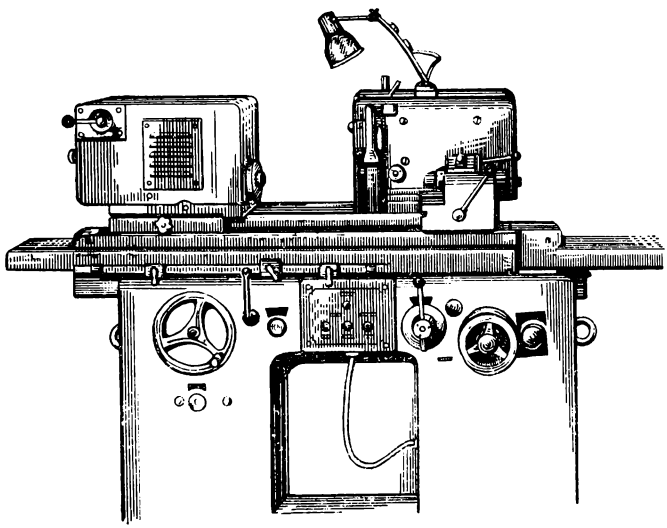


Fig. 81. Universal cylindrical grinder, model 312M

10-2. CONSTRUCTION OF CYLINDRICAL GRINDERS

The principal units and ports of a cylindrical grinder are shown in Fig. 82.

Base *1* accommodates all parts, units and control elements. Its internal space is used for the accommodation of hydraulic devices, and also serves as a reservoir for oil. On the upper surface of the base are accurately machined longitudinal ways, along which table *4* can travel back and forth. The table is traversed by the hydraulic system of the machine. Table traverse is reversed by the turning of lever *7* when it is tripped by dogs *10*.

The two dogs *10* are adjusted along a T-slot on the side of the table and are fixed in the required position, depending on the length and position of the surface of the work to be ground. Handwheel *2* is used in setting up the grinder

or in cases when the conditions of operation require manual table traverse.

Headstock *6* with electric motor *5* for rotating the workpiece is mounted on the machine table.

Work is either held in a chuck or set up between centres. One of the centres is inserted into the tapered hole of the headstock spindle, and the other in footstock *9*. Work is

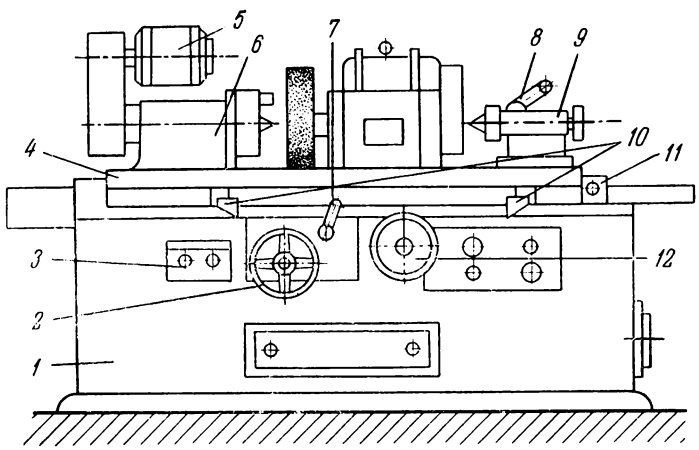


Fig. 82. Principal units and parts of a cylindrical grinder

clamped between the centres by the action of a spring in the footstock. Lever *8* is used to retract the footstock centre or to advance it into the centre hole of the workpiece.

For grinding tapered work with an angle of inclination not exceeding 8 or 10°, the upper part of the table can be swivelled to the required taper angle by means of screw *11*.

Apart from the longitudinal ways, along which the table travels, the base has transverse ways for setting up and traversing the wheelhead.

The wheelhead spindle, which carries the grinding wheel, is driven by a separate motor via V-belts. The speed of the spindle can be varied by changing the pulleys.

Cross travel of the wheelhead for power infeed is effected by the hydraulic system; manual infeed—from handwheel *12* located on the front wall of the base. In some machines, this handwheel is located directly on the wheelhead.

Push-button station *3* is located on the front wall of the base. The oil for the hydraulic system is poured either directly into a compartment of the base designed for this purpose, or into a special tank inside the base. Coolant is poured into a separate tank which is located near the machine or accommodated inside the base.

10-3. CYLINDRICAL GRINDER, MODEL 312M

This Soviet machine tool is designed for the precision external grinding of work from 3 or 5 mm to 50 or 75 mm in diameter. The wheelhead of the machine is also adapted for the internal grinding of cylindrical and tapered holes.

In addition to the upper swivel slide of the wheelhead, there is also a lower swivel plate, which enables work with long tapered surfaces to be ground when the taper angle exceeds 15°.

Base. The base is designed to accommodate the units and components of the machine and is a grey iron casting of rigid construction. A large recess is provided in the middle of the base in front for the legs of the operator, who works sitting down. The base has recesses at both sides in front for housing various mechanisms, and a machined pad in front for mounting the control units.

The internal space of the base is divided into two compartments (Fig. 83). Left compartment *1* houses the oil tank and a hydraulic pump with an electric motor. The hydraulic devices are adjusted through a hatch in the left side of the base. Right compartment *2* contains the coolant tank. Both compartments are closed by a cover.

Recess *3*, in the right-hand side of the base, is for mounting the electrical equipment. Ways are provided on the upper surface of the base for longitudinal travel of the table. The cross section of the ways is shown in Fig. 83. Lubricant is supplied through holes in the middle of the ways and the oil drains to a settling tank from recesses provided at the ends of the ways. The swivel plate of the wheelhead is mounted on an accurately machined pad on the top of the base. To the left of this pad is a rectangular opening for the tank of the primary coolant filter, and a round hole for mounting the coolant pump.

Table. The table (Fig. 84) of the grinder consists of lower sliding table *1* travelling along the base ways and upper swivelling table *3* on which the headstock and footstock are mounted. The lower table is cast integral with guards *11* which protect the ways of the base from abrasive grit and dust. Long shield *6*, screwed to the rear of the table, serves the same purpose.

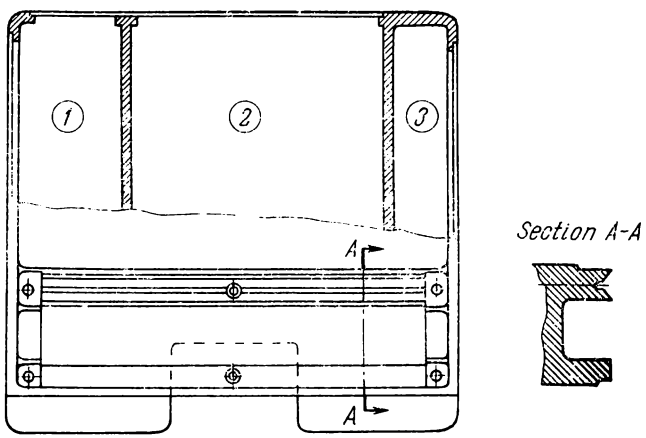


Fig. 83. Base

Bracket *7* is secured by screws under the lower table, and connects the latter to the rod of the hydraulic cylinder. Rack *8*, for hand traverse, is also secured underneath the lower table. The front of the lower table has a T-slot along which are adjusted dogs *9*, for reversing table travel.

Press-fitted into the upper surface of the lower table is pivot *5*. The latter fits into bushing *4* which is press-fitted into the swivel table. The upper table is swivelled about the pivot by turning screw *13*. The angle of table swivel for grinding tapered work is set up on scale *12*.

When the angle in the drawing is specified as a taper instead of in degrees, the second scale is used for setting up the table. The divisions of this scale are shown in units of taper. The table is fixed in the selected position by means of clamping shoes *10* mounted at both ends of the lower table.

The upper surface of the swivel table is of dovetail shape making it more convenient to set up the headstock and footstock accurately and to fix them in position.

For normal and accurate operation of the grinder, the ways of the table and base must be in a good state of repair, clean and free from scratches and notches. In any position of the table, the ways of the sliding table and base must be in full contact.

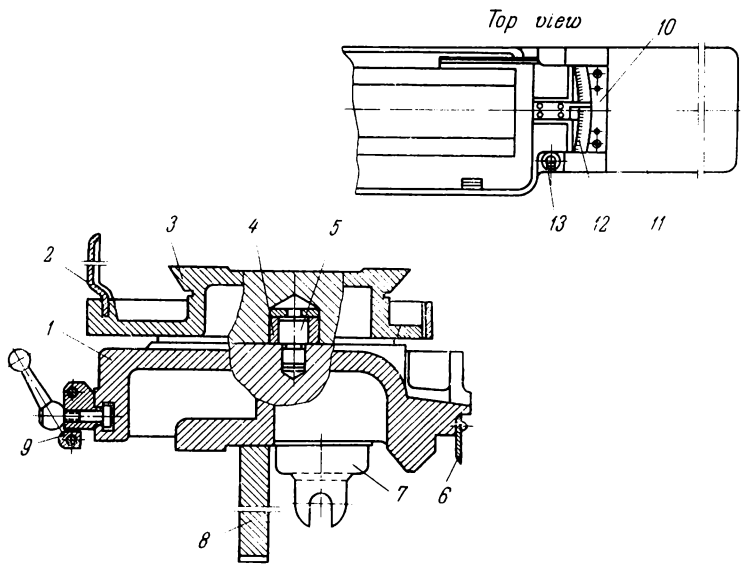


Fig. 84. Construction of the table

If large lots of workpieces which are considerably shorter than the maximum travel of the table (500 mm for this machine) are to be ground, it is recommended that the position of the headstock and footstock should be periodically changed along the surface of the swivel table.

At the front edge of the upper table there is a slot for mounting shield *2*, which protects the operator against the splashing of the coolant.

Hand Table Traverse Mechanism. The construction and kinematic diagram of the mechanism for hand traverse of the table are shown in Fig. 85.

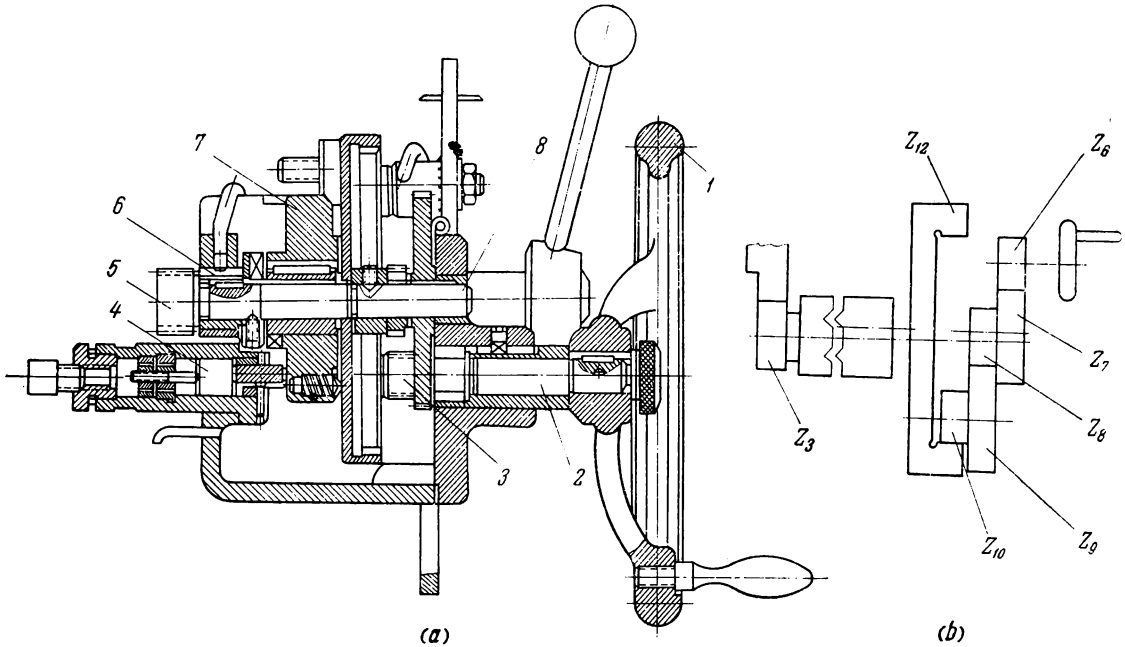


Fig. 85. Hand table traverse mechanism:
a—construction; *b*—gearing diagram

Handwheel *1* is rigidly mounted on shaft *2*, at the other end of which gear *3* is mounted. The handwheel and gear can be shifted axially into either of two positions. When the handwheel is shifted to the right (pulled outwards) gear *3* meshes with large gear z_7 of the double cluster gear. The small gear of this cluster meshes with large gear z_9 of another cluster gear. Both cluster gears are freely mounted on their axles.

Small gear z_{10} meshes with internal gear z_{12}, which is freely mounted on shaft *8*. On the left-hand end of this shaft gear *5* is rigidly mounted. On the hub of gear *5* is clutch member *6* which slides along a feather. This clutch member, under spring action, is continuously engaged with clutch member *7*, which is rigidly secured to shaft *8*, and hence to gear *5*. The latter meshes with the rack of the table.

Thus, after pulling the handwheel outwards and rotating it, the table travel per handwheel revolution (with a table rack module m 2 mm) will be

$$l_1 = \frac{z_6 z_8 z_{10}}{z_7 z_9 z_{12}} \pi m z_3 = \frac{16 \times 23 \times 20}{75 \times 64 \times 107} \times 3.14 \times 2 \times 16 = \frac{2,311}{1,605} \approx 1.4 \text{ mm}$$

If the handwheel is shifted to the left (pushed inwards), gear z_6 meshes directly with internal gear z_{12}, and for one turn of the handwheel, the table is traversed an amount equal to

$$l_2 = \frac{z_6}{z_{12}} \pi m z_3 = \frac{16}{107} \times 3.14 \times 2 \times 16 \approx 15 \text{ mm}$$

The mechanism for hand table traverse operates only when the hydraulic power traverse is disengaged. When hydraulic traverse is engaged, the oil simultaneously enters the working cylinder of the table and the cylinder of a plunger. The latter is shifted and exerts pressure on clutch member *7*, disengaging it from clutch member *6*. If the handwheel is now turned, all the gears will rotate idly for any position of the handwheel.

When hydraulic traverse of the table is disengaged, the clutch members are automatically engaged again and hand table traverse can be used.

The Headstock. The headstock (Fig. 86) effects rotation (circular feed) of the work at the required peripheral speed. It consists of housing *4* mounted on plate *6* by means of locating pivot *8*. The headstock can swivel on this pivot through an angle of 90°. The swivel angle can be read off scale *5*. The housing is fixed at the required angle by screw *7*.

Plate *6* has dovetail ways underneath by means of which the headstock can be adjusted along the upper swivel table; the headstock is fixed in position on the table by two screws *17*.

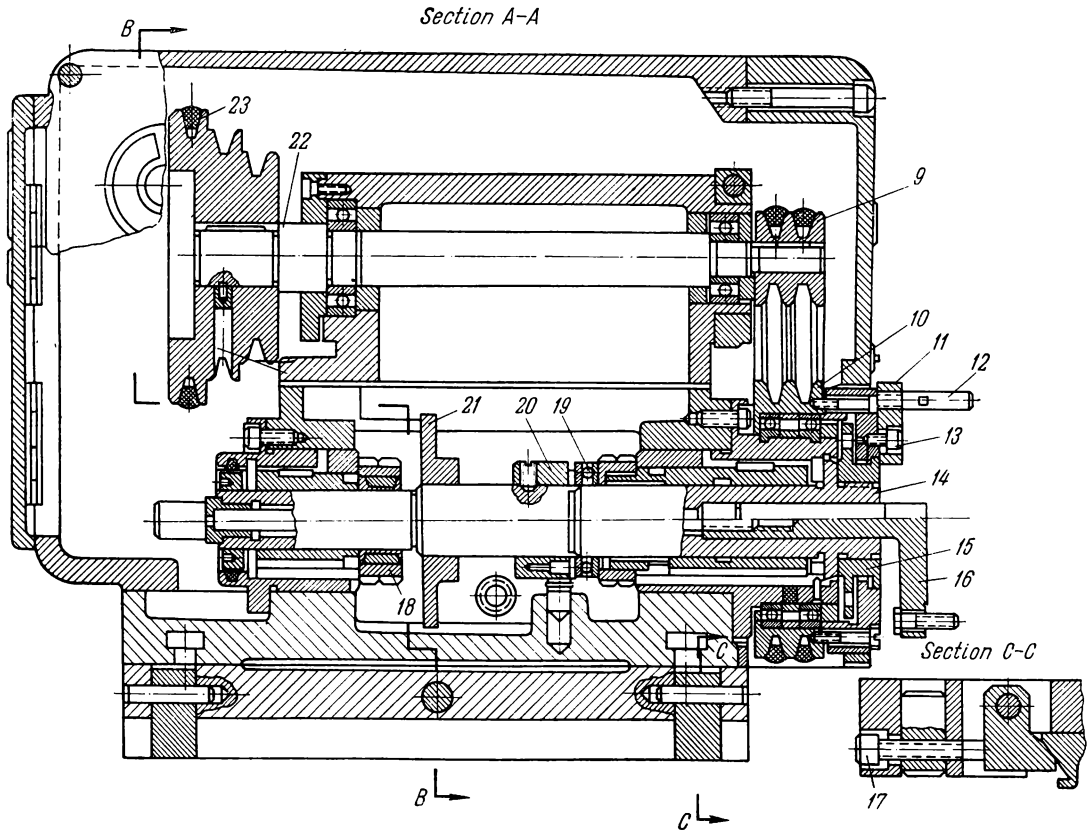
The drive of the headstock is designed as follows. Three-step pulley *1*, mounted on the shaft of two-speed electric motor *2* transmits rotation, by means of a V-belt, to pulley *23*; the latter is mounted at the left-hand end of intermediate shaft *22*. Fitted on the right-hand end of this shaft is pulley *9*, which, by means of two V-belts, transmits rotation to pulley *10*; the latter is linked to faceplate *11*.

At the front end of spindle *14*, bush *15* is rigidly mounted. This bush can be secured to the faceplate by means of screw *13*. Upon switching on the electric motor, the spindle of the headstock begins to rotate. This setup of the headstock is required for grinding in an ordinary chuck or a collet chuck.

Mandrel *16* is used for fixing the chuck. It is inserted into the tapered hole of the spindle and is fastened by a screw. The same screw is used for clamping work held in a collet chuck.

When grinding is carried out between centres, screw *13* is removed and sleeve *15*, being released from faceplate *11*, will not rotate when the electric motor is switched on. The spindle and the inserted centre will remain stationary together with the sleeve. The work, however, will be driven by the faceplate through stud *12* and the driving dog clamped on the end of the work to be ground.

The speed of the headstock spindle depends upon the speed of the electric motor and the position of the belt on pulley *23*. The available spindle speeds are: 150, 250, 300, 400, 500 and 800 rpm. To change the V-belt from one step to another, slide *3*, together with the electric motor, is shifted by means of a screw towards the spindle. When


Section A-A
B
23
22
9
10
11
12
21
20
19
13
14
15
16
18
C
Section C-C
17
B
C

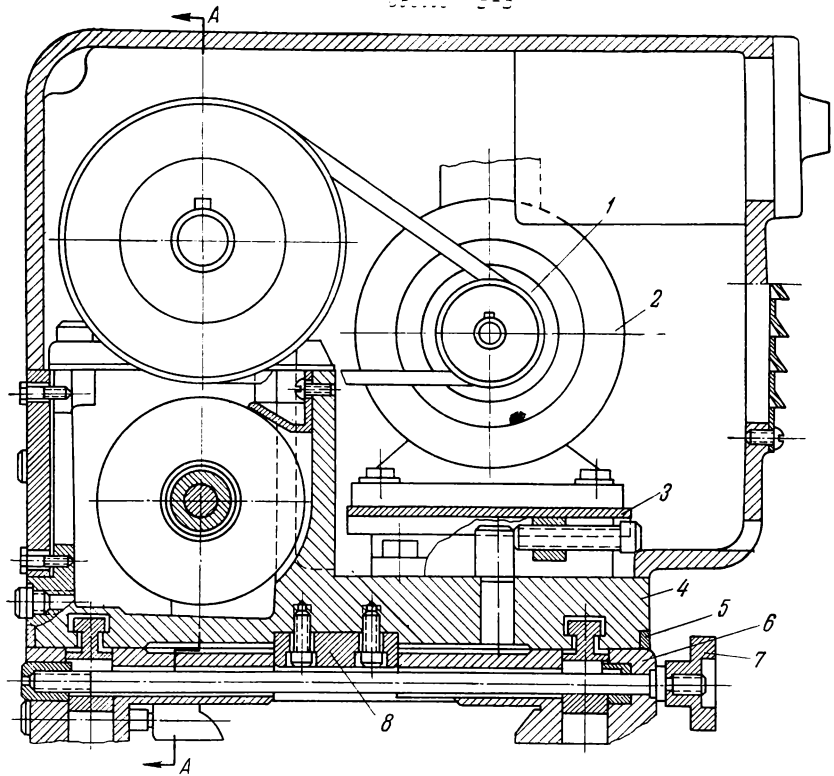


Fig. 86. Headstock

the belt is free, it is shifted to the appropriate step, and the slide is then moved back until the required belt tension is re-established.

The headstock spindle runs in two adjustable sleeve bearings with bronze inserts. Adjustment of the longitudinal clearance between the spindle and bearings is carried out by means of nut *18*, which shifts the insert of the bearing in the appropriate direction. Owing to the external tapered surface of the insert and the corresponding internal tapered surface of the bearing housing, longitudinal displacement of the insert changes the clearance between the spindle journal and the bearing insert. The spindle is prevented from longitudinal movement by means of thrust bearing *19* and supporting sleeve *20*.

The bearings are oiled by means of disk *21*, which is attached to the spindle. The disk, which revolves together with the spindle, entrains oil from the reservoir in the headstock housing and transfers it to a trough, whence it flows along tubing to the places to be oiled.

The Footstock. The function of the footstock (Fig. 87) is to support the right end of the work during grinding between centres. It is mounted on the upper table at a definite distance from the headstock, depending on the length of the work. The footstock is fixed in the required position with a handle of hub *12* mounted rigidly on shaft *13*. When the handle and shaft *13* are turned, the eccentric journal at the left end of the shaft draws up wedge *14* and binds the footstock.

In housing *1* of the footstock, a hole is bored for footstock spindle *3*. Centre *2* is inserted into the right-hand end of the footstock spindle. Spring *7*, acting on this spindle, clamps the work between the centres during the grinding operation. The force exerted by the spring is adjusted by screw *8*, which also serves to push the centre out of the spindle. To eliminate clearance of the spindle in the footstock housing, handle *5* is used. It fixes the position of the spindle by means of screw *6*. When the work is to be mounted between the centres, the footstock centre is retracted to the right by handle *11* and pinion *10*, which meshes with a rack cut on the right end of the footstock spindle. The maximum travel of the spindle is 20 mm.

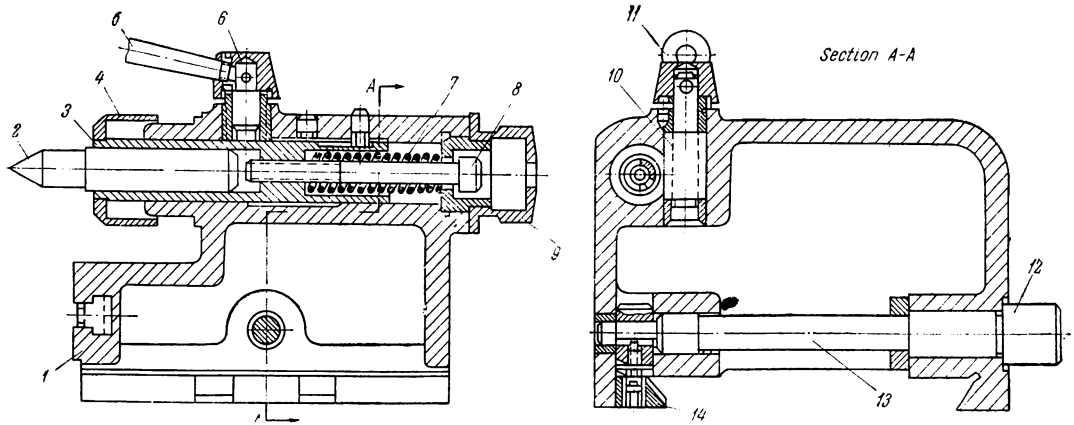


Fig. 87. Footstock

The external surface of the footstock spindle is protected against dust by cap *4* which slides along a turned projection of the footstock when the spindle is extended. There is also protective cap *9* at the rear of the footstock.

Prior to fixing the headstock and footstock in position on the upper table, the mating surfaces of the stocks and the table must be wiped clean.

The Wheelhead. The wheelhead provides the principal cutting motion, which is the rotation of the spindle together with the grinding wheel. A 2.8 kW motor running at a speed of 3,000 rpm drives a grinding wheel 300 mm in diameter through two V-belts, for external grinding. The peripheral speed of a new wheel is 39 m per sec, and that of a wheel worn down to 200 mm in diameter is 26 m per sec.

To carry out internal grinding operations, the wheelhead is swivelled through 180°. The second end of the motor shaft is used for this purpose, and the internal grinding spindle, furnished with the grinder, is set up to obtain the required speed. Two pairs of pulleys supplied with the machine enable two speeds of the internal grinding spindle to be obtained, viz., 8,000 and 15,000 rpm, for grinding holes from 20 to 50 mm in diameter (see p. 224).

Wheel spindle *7* (Fig. 88) runs in sleeve bearings. The axial position of the spindle is fixed from the left by the flange of the spindle, and from the right by a ball thrust bearing *17*. Grinding wheel *4* is mounted on wheel sleeve *1* and is fastened by screws *2*.

The sleeve, together with the grinding wheel, is mounted on the left tapered end (nose) of the spindle and fixed by a central screw with a washer. To prevent slipping of the wheel, the sleeve is keyed on the spindle. In exactly the same manner, pulley *8* is attached to the right-hand end *7* of the spindle and is driven by an electric motor mounted in the housing of the wheelhead, by means of two V-belts.

Wheelhead housing *6* has on its underside an accurately machined surface with which it is mounted on the mating surface of the upper slide. This arrangement enables the wheelhead to be swivelled through any required angle. The angle of swivel is read off scale *5* which is secured to the wheelhead housing.

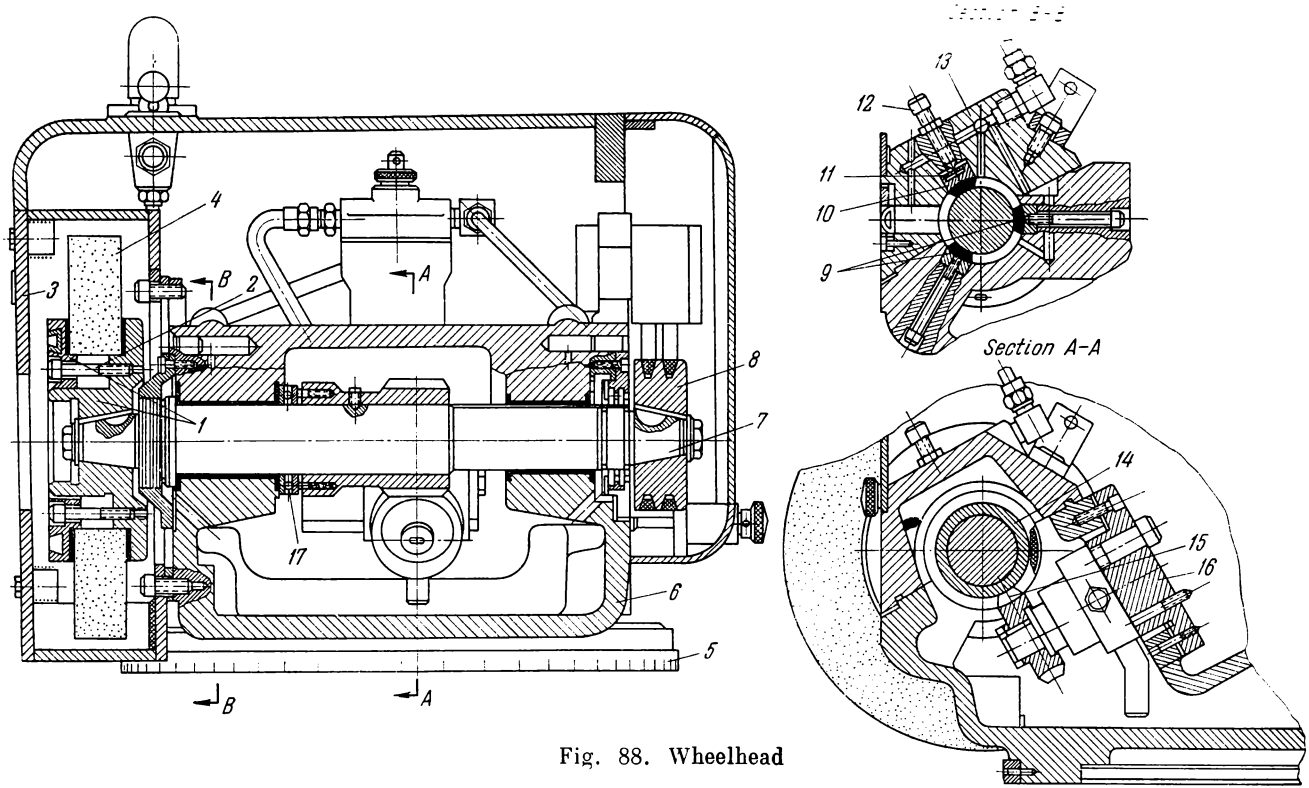


Fig. 88. Wheelhead

The wheelhead is swivelled to the required position and fixed with two T-bolts whose heads enter the circular T-slot of the upper slide.

Guard *3* of the grinding wheel is made of sheet steel, 7.5 mm thick, and is secured by screws to the housing of the wheelhead.

The wheel spindle runs in split bearings. Each bearing consists of two inserts *9*, which are rigidly fixed to the housing, and a third adjustable insert *10*. The force with which the adjustable insert is held against the spindle journal can be adjusted by screw *12* and flat spring *11*.

Fixed inserts *9* of the front and rear bearings are disposed so that they fully take up the load due to the tension of the belts and to the normal component of the grinding force. Thus, the adjustable inserts of both bearings are relieved of the basic stresses developed in the supports. This guarantees stability of operation of the spindle.

The wheelhead bearings are lubricated by special gear pump *16*. The gears of the pump are driven from the spindle, in the centre of which is mounted worm *14* meshing with worm wheel *15* on the pump shaft. Oil delivered by the pump flows through pipes and passages in the housing and bearing cap *13* to the spindle journals. Proper oil flow is observed through the sight oil gauges.

Universal Slide Unit. The function of this unit (Fig. 89) is to carry the wheelhead. Secured under upper slide *14* are vee way *13* and flat way *20* which, through a set of intermediate cylindrical rollers, rest on the corresponding ways secured to the lower swivel slide. At the underside of the latter is a circular way, by means of which the lower swivel slide *12* swivels on wheel base *9*. The swivel angle of the lower slide is read by means of graduated ring *10*, which is secured by screws to base *9*. The lower swivel slide is clamped to the base by T-bolts *11*, the heads of which enter the circular T-slot of the base.

The universal construction of the slide unit is used in grinding long tapered surfaces having an angle of taper more than 15°. Let us assume that the tapered surface of a workpiece with an included angle of 35° is to be ground. To do this, bolts *11* are released and the lower slide is turned counterclockwise through an angle of $90° - \frac{35°}{2} = 72°30'$.

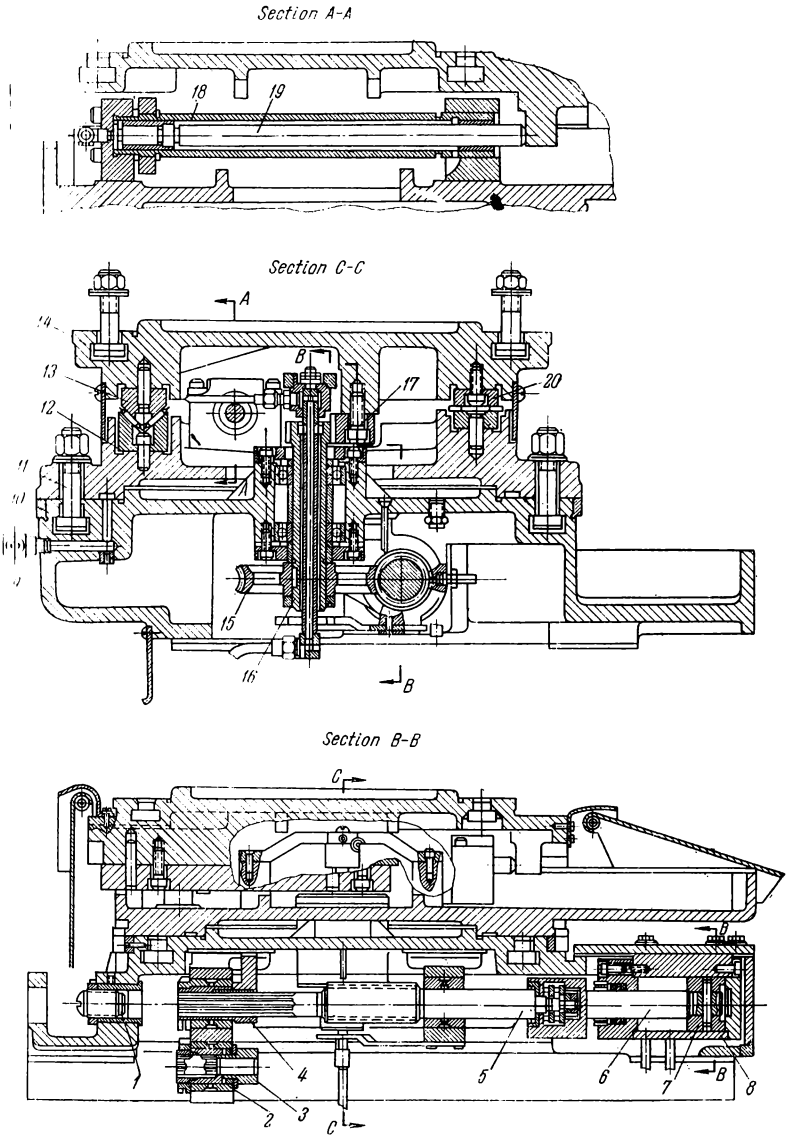


Fig. 89. Universal slide unit

With the slide fixed in this position, the wheelhead is turned clockwise through an angle of 90°.

As a result, the direction of travel of the upper slide, as well as the face of the grinding wheel, will be parallel to an element of the tapered surface to be ground; then the work is ground by traversing the grinding wheel manually with the cross feed handwheel along the entire length of the tapered surface. Infeed in this case is effected with the handwheel for the longitudinal traverse of the table.

The upper slide is traversed by pinion *16*, which meshes with rack *17* screwed to the upper slide. Rigidly mounted on the hub of this pinion is worm wheel *15* which is rotated at different speeds, depending on the required speed of wheelhead traverse.

Backlash between the worm and worm wheel *15*, as well as between pinion *16* and rack *17*, is eliminated by hydraulic cylinder *18* and piston *19*. Hydraulic cylinder *18* is linked to the lower slide, and the right-hand end of the piston *19* bears against a lug of the upper slide. Oil, entering the left end of the cylinder, displaces the piston and eliminates the above-mentioned backlash.

Upon engaging the rapid approach lever of the wheelhead, worm shaft *5*, which is connected to rod *6* of piston *7* in hydraulic cylinder *8*, is displaced axially by the pressure of oil entering the right end of the cylinder. Since it does not revolve, but acts like a rack, the worm turns worm wheel *15*, and with it, pinion *16* which meshes with rack *17* of the upper slide. The length of travel of the upper slide for rapid approach is determined by the position of stop *1*, which is mounted in the wheel base.

Wheelhead Infeed Mechanism. Wheel infeed is effected by the rotation of worm wheel *15* imparted by worm shaft *5* (Fig. 89). Mounted on the splined end of worm shaft *5* is gear *4*, meshing with gear *3*. The latter is rigidly linked to splined sleeve *2*. The splined end of shaft *8* (Fig. 90) of the wheel infeed mechanism fits into the splined hole of this sleeve.

Shaft *8* runs in ball bearings in sleeve *7*, which is secured in plate *6*. The plate is attached to the front wall of the base by screws *9* and two dowel pins. Ratchet wheel *10* is rigidly mounted on the shaft. Bushing *12*, secured to dial *3*, sits freely on shaft *8*.

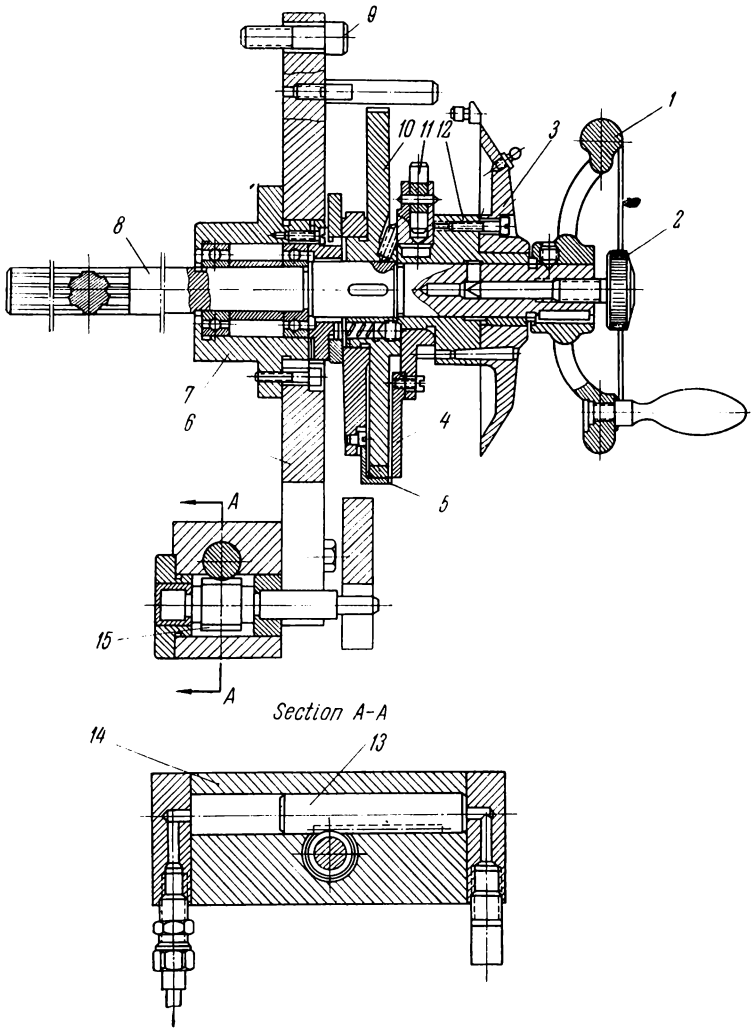


Fig. 90. Wheel infeed mechanism

When the bushing with the dial has been set to the required angular position, it is secured by screw *2*. The conical, left end of the latter spreads apart three clamping pins situated in radial holes in the shaft of the mechanism.

Fixed on the right end of shaft *8* is handwheel *1*, by means of which hand feed of the wheelhead is effected.

When the valve is opened, oil enters cylinder *14* and shifts rack plunger *13*, which rotates pinion *15*. The latter is linked to the pawl of the ratchet wheel. In each stroke of the plunger, the pawl revolves the ratchet wheel by 10 teeth, which constitutes the maximum infeed. If a lesser rate of infeed is required, shield *5* is turned so as to cover a portion of the teeth of the ratchet wheel. When the work being ground has reached the given size shield *4*, which is linked to dial *3*, lifts the pawl from the ratchet wheel and thus disengages the infeed.

Grinding may be performed by manual infeed *to the dial scale* or *to a positive stop*. In the first method, a test piece is ground to the required size and the dial is set to zero after releasing screw *2*. Then the wheelhead is withdrawn by an amount slightly greater than one half of the grinding allowance. In grinding subsequent workpieces, the wheelhead is infed by the handwheel until the zero graduation of the dial scale reaches the index line.

In the second method, after grinding the test piece to final size, bushing *12* is set so that pin *11* of the rigidly mounted disk bears tightly against the stop. Subsequent workpieces are ground to size by turning the handwheel until the stop is reached. The gradual decrease in diameter of the grinding wheel due to wear must be compensated for by resetting the dial.

In both methods, care must be taken so that bushing *12* and the dial are not displaced on shaft *8*, since this may result in undersized work that must be rejected.

10-4. HYDRAULIC SYSTEM OF THE MODEL 312M GRINDER

In the cylindrical grinder, model 312M, the following functions are hydraulically operated:

(1) longitudinal traverse of the table;

(2) automatic infeed upon each stroke of the table;

(3) rapid approach and withdrawal of the grinding wheel;

(4) automatic disengagement of the hand table traverse mechanism;

(5) elimination of backlash in the wheelhead infeed mechanism.

Longitudinal Traverse of the Table. Vane pump *21* (Fig. 91) draws the oil from the tank and delivers it through filter *22* to the hydraulic control panel *5*. Relief valve *20* serves to protect the hydraulic system against pressure fluctuations.

When valve *6* on the hydraulic control panel is set to the START position and reversing lever *3* is shifted to the right, the reversing valve spool *19* will be shifted to the left and oil under pressure will enter the right end of the working cylinder *10* forcing piston *11* to the left. Piston rod *12* is connected to the table. At the same time, oil from the left end of the working cylinder passes through throttle valve *18* in the panel after which it drains back to the tank.

When the travelling table with fixed dog *4* shifts the reversing lever *3* to the left, control valve spool *17* is shifted and admits oil to the left end of the reversing valve spool *19*, moving the latter to the right. Oil will then pass to the left end of the working cylinder and the table will begin to move in the opposite direction (i.e., to the right).

Lever *3*, which operates reversing valve *19* and changes the direction of table travel, can be shifted manually. The time during which the table reverses can be regulated by throttle valves *1* and *2*. The speed of the table travel (the rate of longitudinal traverse) is regulated by throttle valve *18*.

If hand table traverse is to be engaged, valve *6* is turned from the START to the STOP position. Reversing valve *19* is thereby disconnected from the delivery line and both ends of cylinder *10* are connected together. This enables the table to be traversed by hand.

Power Infeed of the Table. At the end of each stroke of the table, simultaneously with the admission of oil to one end of reversing valve *19*, oil also enters the right (or left) end of cylinder *27*. This causes the displacement of plunger rack *26*, which turns gear *28*. The latter is connected to

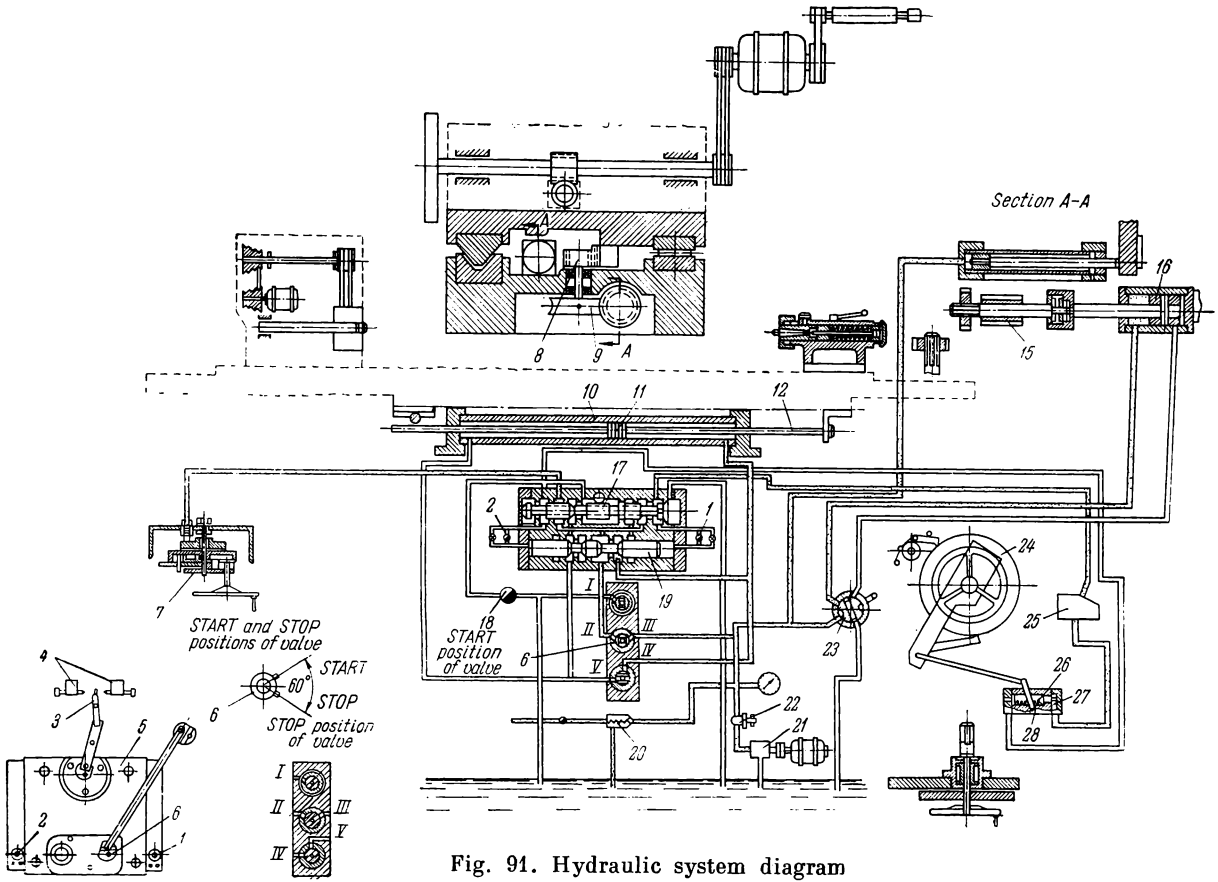


Fig. 91. Hydraulic system diagram

a crank mechanism. Upon each revolution of the crank, the pawl of ratchet wheel *24* makes one double stroke (back and forth). The ratchet wheel is connected to the shaft of the infeed mechanism. The dimensions of cylinder *27* are so calculated that the time required for plunger *26* to make a complete stroke does not exceed the time required for the operation of reversing valve *19*. This is necessary in order to ensure that infeed takes place when the table is reversing. Power infeed can be disengaged by valve *25*.

Rapid Approach and Withdrawal of the Grinding Wheel. By-passing the hydraulic control panel, oil from the pump passes to valve *17* and hence to the right or left end of cylinder *16*. This displaces the rod and worm *15* linked to it. In this case the worm does not rotate but acts as a rack, rotating a worm wheel and a pinion, the latter being engaged with the rack of the wheelhead slide. This motion results in rapid approach or withdrawal (depending on the position of valve *17*) of the grinding wheel.

Automatic Disengagement of the Hand Table Traverse Mechanism. The mechanisms for manual and hydraulic traverse of the table are interlocked, i.e., the engagement of one automatically leads to the disengagement of the other. This occurs in the following manner. Upon starting hydraulic traverse of the table by turning valve *6*, oil enters under the plunger and, overcoming the action of the spring, shifts toothed clutch *7*. This disengages the rack pinion for longitudinal traverse of the table from the hand feed mechanism.

When valve *6* (Fig. 91) is turned to the STOP position, the clutch is automatically re-engaged.

Backlash Elimination in the Infeed Mechanism. Backlash is eliminated by the action of the plunger of the hydraulic cylinder, on the left end of which pressure is exerted by the oil entering after having by-passed the hydraulic control panel. The oil pressure begins to act on this plunger when the hydraulic pump is switched on, and ends when it is switched off.

Wheel Infeed. Infeed of the grinding wheel is accomplished in the following manner.

Gear *14*, mounted on the shaft of the handwheel, meshes with gear *13* mounted on the shaft of worm *15*. The worm rotates worm wheel *9*, mounted on one shaft with pinion *8*.

The latter rotates and thereby shifts the rack, and with it, the wheelhead slide.

The rate of infeed of the wheel per revolution of the handwheel is

$$l = \frac{z_{37}}{z_{36}} \frac{k_{38}}{z_{30}} z_{29} \pi m$$

where z = number of teeth of the appropriate gear in the gearing diagram
k_{38} = number of starts of the worm
m = module of the rack pinion.

The advantages of hydraulically operated grinding machines are their great versatility, the large number of diverse motions, provided by hydraulic mechanisms of comparatively small size, and stepless variation of the working speed or auxiliary movement within a wide range.

The disadvantages of hydraulically operated machines are their relatively high cost and the unavoidable leakage of oil from the various units of the hydraulic system.

10-5. SETTING UP THE MODEL 312M GRINDER FOR INTERNAL GRINDING

In the universal cylindrical grinder, model 312M, the housing for mounting the internal grinding spindle is cast integral with the wheelhead housing. In setting up the machine for internal grinding, the wheelhead is turned through 180° and the driving belt of the external grinding spindle is removed. The appropriate pulleys are then mounted on the shaft of the motor and on the internal grinding spindle.

Two pairs of pulleys are supplied with the machine, their diameters being: (1) 180 and 30 mm and (2) 135 and 45 mm. The first pair of pulleys gives the spindle a speed of 15,000 rpm, and the second pair, 8,000 rpm. The pair of pulleys chosen for mounting depends on the diameter of the hole to be ground. For instance, if the hole to be ground is 35 mm, the diameter of the grinding wheel should be 30 mm.

For a wheel diameter of 30 mm and a spindle speed of 15,000 rpm, the peripheral speed of the wheel will be

$$v_{wh} = \frac{\pi dn}{60 \times 1{,}000} = \frac{3.14 \times 30 \times 15{,}000}{60 \times 1{,}000} = 22.5 \text{ m per sec}$$

Such a peripheral speed is attained by using the pair of pulleys 180 and 30 mm in diameter. The first pulley is mounted on the shaft of the motor, and the second, on the spindle.

The footstock is not used in internal grinding; it is shifted to its extreme right-hand position, or completely removed from the table. In internal grinding, the mechanisms of table traverse and wheel infeed operate in the same way as in external grinding.

10-6. LUBRICATION AND COOLING SYSTEMS OF THE MODEL 312M GRINDER

Lubrication. The table and wheelhead slide ways, as well as the wheelhead mechanisms, are lubricated automatically with oil which enters a special tank when oil is drained from the hydraulic cylinders. The oil is distributed by pipes to the points to be lubricated.

The bearings of the wheel spindle are lubricated by a mixture consisting of nine parts of kerosene and one part of Industrial oil 20. The mixture is poured into the wheelhead housing. A special gear pump delivers the lubricating mixture into the bearings.

The work spindle bearings are lubricated with oil from a trough, to which it is supplied from a reservoir in the wheelhead housing by means of a disk which revolves together with the spindle. Oil in the reservoir is replenished with Industrial oil 20, filling being performed up to the mark on the sight oil gauge. The table traverse and infeed mechanisms are lubricated by oil which flows down through tubing from the ways.

Cooling. The coolant tank is filled with a 3% solution of grinding emulsion. Every two or three weeks the coolant must be changed and the tank cleaned, and in addition the inserted settling tank must be cleared of accumulated sludge

(sediment). For this purpose, the tank is removed from the base and, after cleaning, is replaced and filled with fresh coolant.

10-7. SEMIAUTOMATIC CYLINDRICAL GRINDER, MODEL 3152

The semiautomatic cylindrical grinder, model 3152 (Fig. 92), is designed for plunge-cut grinding. In many respects it is similar to the universal cylindrical grinder, model 312M.

In small-lot production, the semiautomatic grinder is used for grinding work by means of manual control; under conditions of large-lot or mass production, the machine functions on a semiautomatic cycle.

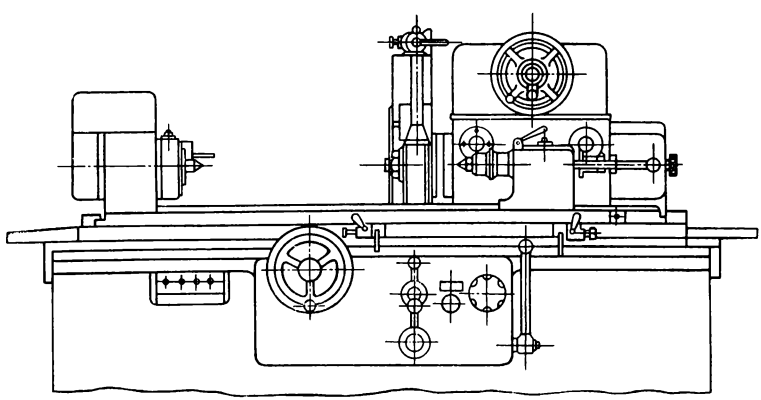


Fig. 92. Semiautomatic cylindrical grinder, model 3152

The semiautomatic cycle includes operations in the following sequence:

(1) setting up the work by hand between the centres, and starting the machine for the automatic cycle;

(2) rapid approach of the wheelhead to the workpiece with simultaneous engagement of work spindle rotation and starting of the coolant flow;

(3) rough grinding, in the course of which 75 to 80% of the surplus stock is removed;

(4) change-over from rough to finish grinding, in the course of which the remaining surplus stock is ground off at a low rate of infeed;

(5) disengagement of the infeed and "sparking out";

(6) rapid withdrawal of the wheelhead, disengagement of work spindle rotation and shutting off of the coolant flow;

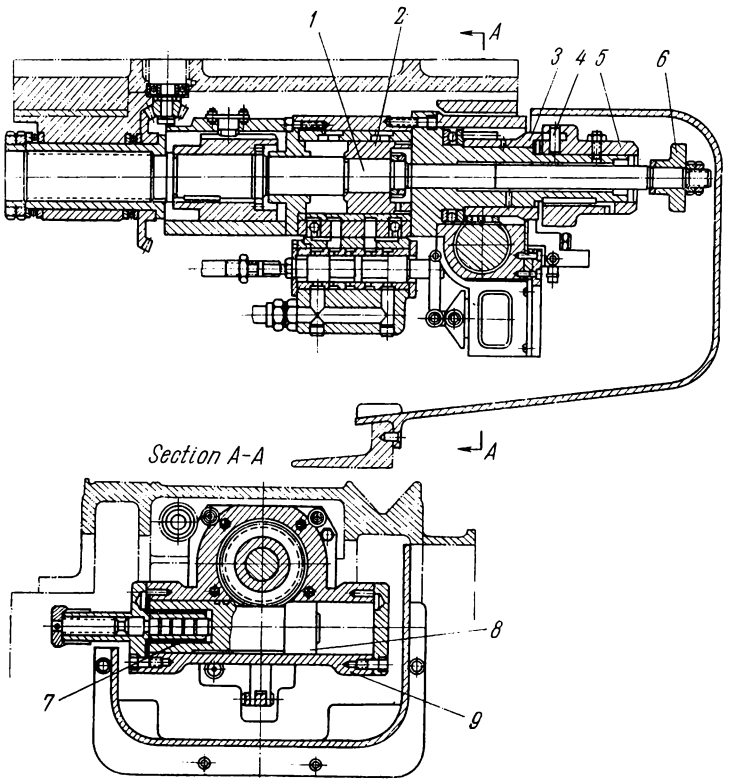


Fig. 93. Mechanism for rapid approach and withdrawal of the wheelhead

(7) removal of the finished workpiece by hand and setting up of a new workpiece.

Fig. 93 shows the mechanism for the rapid approach and withdrawal of the wheelhead, and also for changing the rate of infeed in rough and finish grinding.

After setting up the workpiece and switching on the automatic cycle, oil under pressure enters the right end of hydraulic cylinder *2*, and pushes the piston and rod *1* to the left. The latter advances the wheelhead towards the workpiece until disk *6*, mounted on the right end of piston rod *1*, runs up against sleeve *5*, mounted on the piston rod.

After the rapid approach of the wheelhead the working infeed begins first for rough and, subsequently, for finish grinding.

The change in the rate of infeed takes place as follows.

Roller *4*, mounted at the left end of sleeve *5*, bears against the profile of cam *3*. Upon rotation of cam *3* with respect to sleeve *5*, the latter, under the constant pressure of disk *6*, will advance piston rod *1*, and with it, the wheelhead, towards the workpiece at a rate which depends on the shape of the profile of cam *3*. Roughing infeed corresponds to the steeper portion of the cam profile, and finishing infeed, to the more gently sloping one. For sparking out, the appropriate portion of the working profile of cam *3* is made parallel to the face of sleeve *5*.

Cam *3* is rotated as follows. Hydraulic cylinder *9* with piston *8* is arranged perpendicular to piston rod *1*. A gear rack, cut on the rod of piston *8*, meshes with a gear that is integral with cam *3*.

At the instant when the rapid approach of the wheelhead towards the work ceases, oil begins to flow into the right end of hydraulic cylinder *9*, and the rod of piston *8*, moving to the left, rotates cam *3* through its gear.

At the end of sparking-out operation, the left end of the rod of piston *8* reaches stop *7*, the direction of the oil flow changes, and it enters the left ends of hydraulic cylinders *2* and *9*; the wheelhead is rapidly withdrawn, and the automatic cycle ends.

In mass production, when a large number of semiautomatic grinders of this type are available, the machines are equipped with special automatic loading devices which exclude the manual loading and unloading operations. Such loading devices transform the semiautomatic machines into fully automatic ones.

10-8. INTERNAL GRINDERS

Internal grinding machines are used to grind cylindrical and taper holes, as well as the faces of the workpieces.

Internal grinding differs radically from external grinding. In external grinding, the wheel diameter is independent of the diameter of the work, and is chosen to suit the size and power of the machine, whereas in internal grinding, the grinding wheel enters the hole to be ground, and evidently it must always be smaller than this hole.

In grinding holes less than 40 or 50 mm in diameter the peripheral speed of the grinding wheel is considerably less than that of a wheel used for external grinding. For instance, in grinding a hole 12 mm in diameter with a wheel 10 mm in diameter, at a spindle speed of 15,000 rpm, the peripheral speed of the wheel will be 8 m per sec.

Owing to the greater length of the contact arc between the grinding wheel and the work, the intensity of heat generation in internal grinding is higher than that in external grinding. Moreover, in internal grinding, the conditions of cooling of the grinding zone with grinding fluid are more difficult. The conditions for the removal of chips and dust from the grinding zone are also less favourable.

Rotation of the wheel spindle is the primary cutting motion in internal grinding. Circular feed (work rotation) is effected by the headstock or work spindle, which is powered by a separate electric motor.

Longitudinal traverse is effected by the reciprocating motion of the table. The wheelhead usually moves together with the table, relative to the fixed headstock.

In machines designed for the grinding of small workpieces, the wheelhead may be stationary while the headstock travels together with the table.

According to the method used to drive the work, internal grinding machines are divided into chucking grinders, in which the work is gripped in a chuck or other clamping device mounted on the work spindle, and centreless machines, in which the work is supported and driven by an arrangement consisting of three rolls: the pressure roll, support roll and the regulating roll, or wheel.

10-9. INTERNAL GRINDER, MODEL 3250

The internal grinder, model 3250, which is designed for chucking operation, has four drive motors: a 4.2 kW motor for the wheelhead running at 2,000 rpm; a 0.85 kW motor for the headstock running at 960 rpm; a 1.2 kW motor

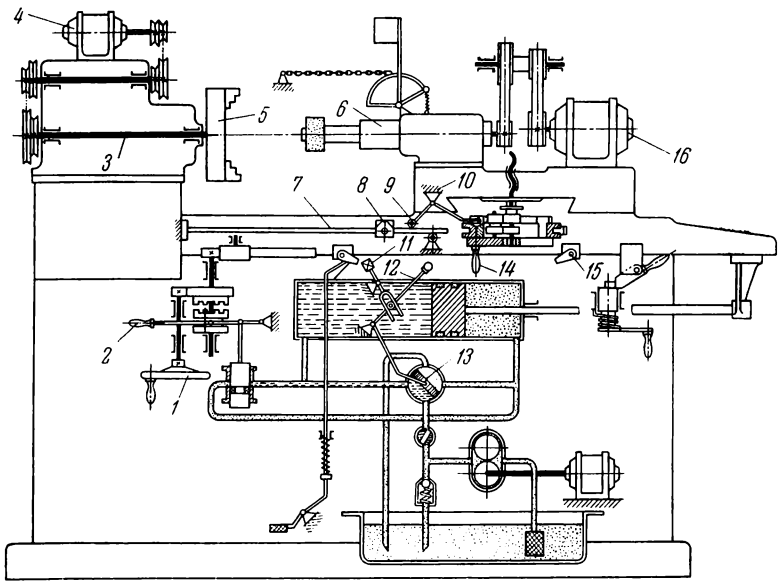


Fig. 94. Hydraulic and kinematic diagram of the internal grinder, model 3250

for the hydraulic pump, and an electric coolant pump motor.

The wheel spindle has three speeds, 8,000, 12,000 and 15,000 rpm depending on the sizes of the mounted interchangeable pulleys. The work spindle has four speeds: 128, 178, 243 and 340 rpm. Hydraulic traverse speeds of the table range from 250 to 8,000 mm per min. The largest diameter of hole which can be ground is 200 mm, and the least, 40 mm.

The Headstock. Spindle *3* of the headstock (Fig. 94) is driven by separate electric motor *4* via a V-belt. Universal (self-centring) chuck *5* or a pneumatic clamping device

is mounted on the nose of the spindle. The headstock is fixed during operation. For grinding tapered holes, it is swivelled to the required angle.

Wheelhead. Mounted in the wheelhead is interchangeable spindle *6*, which is powered by electric motor *16* via a belt transmission.

The grinding wheel is mounted on an interchangeable mandrel, the length and diameter of which depend on the dimensions of the work to be ground.

Infeed of the Grinding Wheel. Infeed is effected manually or by power, by moving the wheelhead crosswise on the dovetail ways of the table. These ways are perpendicular to the base ways.

Manual feed of the wheelhead is from handwheel *14*, mounted on a feed screw. The handwheel drives the feed screw through planetary gearing arranged inside the handwheel and having a gearing ratio of 1 : 6. Thus, for a screw pitch $t = 3$ mm, the wheelhead will be fed

$$\frac{1}{6} \times 3 = 0.5 \text{ mm}$$

for each revolution of the handwheel.

Automatic, or power, infeed of the wheelhead is carried out as follows. Bar *7*, along which cam *8* can be adjusted, is fixed to the base. This cam can be set and clamped at any point along the bar, at the required distance from the headstock.

Lever *9* swings about pin *10* at the front end of the wheelhead. When the table moves to the left, together with the wheelhead, lever *9* runs up on the bevel of cam *8*. This turns the lever whose other end actuates a pawl which turns a ratchet wheel, rigidly attached to handwheel *14*. The ratchet wheel has 250 teeth.

The mechanism by which the pawl is rotated can be adjusted so that each time lever *9* engages cam *8* (this occurs upon each double stroke of the table), the pawl turns the ratchet wheel by the required number of teeth (1 to 6).

Thus, upon each double stroke of the table (back and forth), the automatic infeed (depth of cut) is

$$t = \frac{a}{z} \frac{1}{6} s_{fs}$$

where a = number of teeth engaged by the pawl
z = number of teeth on the ratchet wheel
s_{fs} = pitch of the wheelhead feed screw.

For the data given above

$$t = a \frac{3}{250 \times 6} \text{ mm} = 0.002a \text{ mm}$$

The minimum infeed per double stroke of the table for $a = 1$ is $t_{min} = 0.002$ mm, and the maximum, $t_{max} = 0.012$ mm.

Longitudinal Traverse. The longitudinal reciprocating motion of the table and grinding head (traverse) is effected by the hydraulic piston. Two dogs *15* are set up in the T-slot of the table; their position depends on the position and length of the surface to be ground.

At each end of the table stroke, one of the dogs engages lever *11* and shifts it, thereby operating four-way valve *13*. This changes over the direction of oil flow to the cylinder, and hence the direction of table travel.

The table can also be reversed manually by shifting lever *12*, which is connected to valve *13*. In setting up the machine, the table is traversed by turning handwheel *1*, which drives a rack pinion through gearing. The rack is rigidly attached to the table.

To engage hand table traverse, a claw clutch is engaged by means of lever *2*. This simultaneously shifts a small piston which joins the right and left ends of the hydraulic cylinder. After this, the table can be traversed manually.

10-10. CENTRELESS GRINDING

Centreless grinders are widely used at the present time for grinding large quantities of identical workpieces. These machines have a high output owing to the substantial reduction of handling time (not more than 2 or 3% of the machine time), and enable work with less allowance and of very small diameter to be ground. Centreless grinders are easy to operate.

In the process of grinding in a centreless grinder, the work being ground passes between two abrasive wheels, *2* and *3* (Fig. 95), and is supported on work-rest blade *1*. Regulating wheel *3* drives the work and rotates with a cir-

cumferential speed of 10 to 50 m per sec. Grinding is performed by wheel *2* which rotates at a circumferential speed of 30 to 40 m per sec.

Cylindrical workpieces of the same diameter, or stepped work on which the larger diameter is to be ground, are ground by the through-feed grinding method. Any intermediate diameter or the smallest diameter of stepped workpieces is ground by the infeed method.

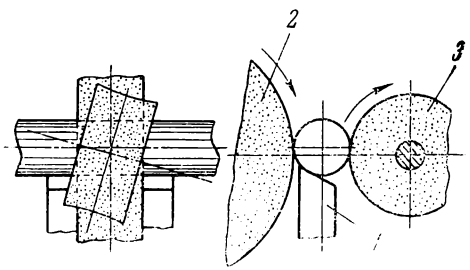


Fig. 95. Diagram of centreless grinding

In through-feed centreless grinding, the regulating wheel imparts not only a rotary but also a longitudinal motion to the work. For this purpose, the axis of the regulating wheel is set at an angle to the axis of the grinding wheel. The greater the angle of inclination, the greater will be the longitudinal feed, or work traverse rate. The supporting surface of the work-rest blade is set parallel to the axis of the grinding wheel. Vertically the blade must be set so that the axis of the work is 0.15 to 0.2 times its diameter above the line of centres of the grinding and regulating wheels. For the centreless grinding of stepped work by means of the infeed method, the regulating wheel is set parallel to the grinding wheel. Work with longitudinal grooves cannot be ground in centreless grinders.

Centreless grinders are also widely used for grinding holes in work after the external surfaces have been ground.

10-11. CENTRELESS GRINDER, MODEL 3180

The centreless grinder, model 3180, manufactured by the Moscow Internal Grinding Machine Plant, is designed for grinding cylindrical, tapered and formed work between 5

and 75 mm in diameter. The gearing diagram of this machine is shown in Fig. 96.

Grinding wheel spindle *3* is powered by 13 kW motor *5*, through a V-belt drive with pulleys *1* and *8*. The grinding wheel is trued and dressed by device *10* mounted on the wheelhead.

In the model with the mechanical drive of the regulating wheel, the wheel is driven by electric motor *18* via chain transmission *17*, a pair of change gears *16*, and worm gearing *15*. The change gears enable eight steps of regulating wheel speed to be obtained between 13 and 94 rpm. When it is being dressed, the regulating wheel is driven by crossed helical (spiral) gears *14* at the dressing speed (225 rpm).

In the hydraulic regulating wheel drive model, a separate electric motor *4* and a gear pump are used. The pump delivers oil under pressure to hydraulic motor *2*. The pressure can be regulated by high-pressure valve *7*. The hydraulic motor drives the regulating wheel in a stepless range from 25 to 225 rpm, which includes the entire range of working speeds (25 to 100 rpm), as well as the speed required for dressing (225 rpm).

Oil draining from the hydraulic system of the regulating wheel drive passes to the grinding wheel bearings for the purpose of lubrication and cooling, and also to hydraulic cylinder *9* of the device for dressing the grinding wheel. The pressure of the oil is regulated by valve *6*. The regulating wheel is dressed by turning handwheel *12* of dressing mechanism *11*.

Centreless grinder, model 3180, can be equipped with a loading device, in which case it will operate like an automatic machine. In the automatic grinding cycle, the diameter of the work being ground must be periodically checked, as it will gradually increase in the course of grinding and regulating wheel wear. When the actual diameter of a workpiece exceeds the upper tolerance limit, the regulating wheelhead is advanced towards the grinding wheel by the amount required to obtain the specified diameter again within the tolerance limits.

The regulating wheelhead is traversed in setting up the grinder, as well as for hand infeed, by handwheel *13*, through gearing and a screw and nut.

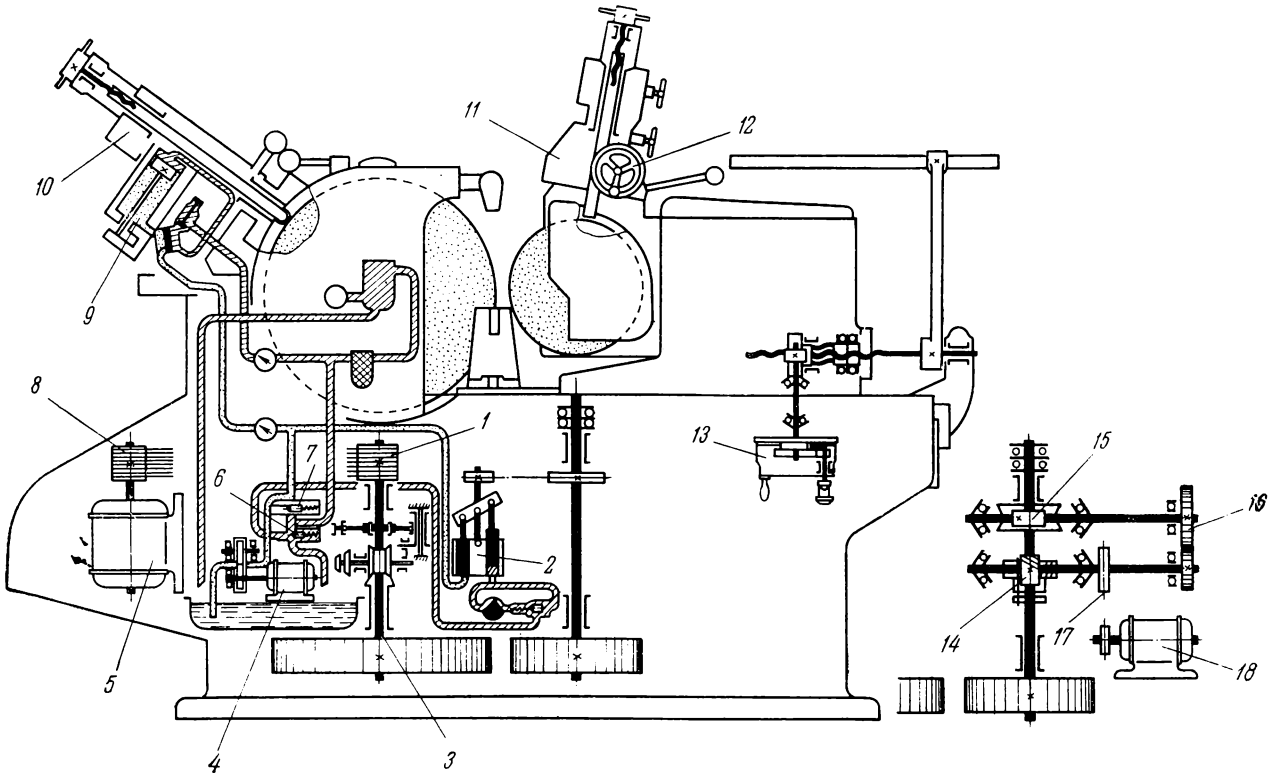


Fig. 96. Kinematic diagram of the centreless grinder, model 3180

At present, various devices are used which automatically reset the machine to the required size to be ground. Such devices are called *automatic gauging control systems.* The main element of such a system is the gauging device—a sensitive element which, during the working process of the machine, constantly checks the actual size of the work being ground, and automatically engages and disengages the feed mechanism of the regulating wheelhead, as required.

10-12. SERVICE MANUAL OF A MACHINE TOOL

Purpose and Contents of the Service Manual. The service manual contains essential information required for the proper and efficient use of the machine. It indicates the limiting sizes of surfaces which can be machined, the degree of accuracy which can be obtained by the correct use of the machine, information on the speeds of the spindles and moving units, and the characteristics of the gears, worms, worm wheels, racks, screws, nuts and ratchet wheels installed in the machine or supplied with it as spares.

The service manual contains the kinematic diagram of the machine and a general view with a list of the control levers and devices.

An intimate acquaintance with the contents of the service manual is essential for each operator. The information given in the manual is also required for each foreman and process engineer to ensure that the machine is being correctly used.

Use of the Service Manual to Select Speeds and Feeds. Let us select the speeds and feeds (cutting conditions) for rough grinding a shaft 50 mm in diameter and 320 mm in length.

We shall begin with the following tentative values: peripheral speed of the wheel $v_{wh} = 30$ m per sec, peripheral speed of the work $v_w = 35$ m per min, traverse rate $s = 0.8\ H$ (H is the wheel width), infeed $t = 0.015$ mm per table stroke.

Using the data of the service manual, let us determine the final values.

(1) If the rotational speed of the spindle of the grinding wheel n_{wh} = 2,500 rpm and the required peripheral speed v_{wh} = 30 m per sec, the diameter of the grinding wheel D is determined as follows

$$v_{wh} = \frac{\pi D n_{wh}}{60 \times 1{,}000}$$

or

$$30 = \frac{3.14 \times D \times 2{,}500}{60 \times 1{,}000}$$

whence

$$D = \frac{30 \times 60 \times 1{,}000}{3.14 \times 2{,}500} = 230 \text{ mm}$$

For a wheel diameter of 250 mm

$$v_{wh} = \frac{3.14 \times 250 \times 2{,}500}{60 \times 1{,}000} = 32 \text{ m per sec}$$

This value obtained for the peripheral speed of the wheel differs little from that given, and hence we accept this speed as the final one.

(2) For v_w = 35 m per min and a work diameter d = = 50 mm, the work spindle speed is determined in the following sequence

$$v_w = \frac{\pi D n_w}{1{,}000}$$

or

$$35 = \frac{3.14 \times 50 \times n_w}{1{,}000}$$

whence the rotational speed of the work is

$$n_w = \frac{35 \times 1{,}000}{3.14 \times 50} = 223 \text{ rpm}$$

From the service manual, the nearest available work speed is found, namely, n_w = 250 rpm. For this speed, the peripheral speed of the work is

$$v_w = \frac{\pi d n_w}{1{,}000} = \frac{3.14 \times 50 \times 250}{1{,}000} = 39 \text{ m per min}$$

The work speed obtained differs substantially from the tentative value, but must be accepted as the final one, since the nearest lower value according to the service manual,

namely, $n_w = 150$ rpm, leads to an even greater difference.

(3) The rate of traverse for a wheel width $H = 40$ mm will be $s = 0.8\ H = 0.8 \times 40 = 32$ mm. For a shaft length of 320 mm, the wheel will make one pass for 10 revolutions of the shaft (work). For a work speed of $n_w = 250$ rpm

$$\frac{10}{250} = 0.04 \text{ min}$$

will be required per 10 revolutions.

Hence the required table traverse speed is

$$v_t = \frac{320}{0.04 \times 1{,}000} = 8 \text{ m per min}$$

According to the service manual, the maximum table traverse speed v_t is 6 m per min. Therefore a traverse speed of $0.8\ H$ cannot be obtained.

Let us determine the traverse speed in terms of the wheel width for $v_t = 6$ m per min.

If the sought fraction of the wheel width is denoted by X, the travel of the table (in mm per min) can be expressed in the following way

$$6{,}000 = XHn_w$$

whence

$$X = \frac{6{,}000}{Hn_w} = \frac{6{,}000}{40 \times 250} = 0.6$$

(4) Let us assume an infeed of 0.015 mm per table stroke. Then handle *13* must be set for the following number of teeth to be engaged by the pawl of the ratchet wheel

$$z = \frac{0.015}{0.0025} = 6$$

Thus the actual values of the speeds and feeds will be

$$v_{wh} = 32 \text{ m per sec}, \quad v_w = 39 \text{ m per min},$$

$$s = 0.6\ H, \quad \text{and} \quad t = 0.015 \text{ mm per table stroke.}$$

10-13. OPERATING ACCURACY OF A GRINDING MACHINE

Accuracy Tests. The accuracy of a grinding machine greatly affects the dimensional accuracy of the ground work. Accuracy tests are conducted when the machine

not in operation (static tests), as well as during operation (dynamic tests). In the static tests of grinding machines, the following are checked:

(1) bearing contact between the table and base ways;

(2) horizontal position of the table in the longitudinal and transverse directions;

(3) straightness of the base ways and the surfaces on which the headstock and footstock are mounted;

(4) axial runout of the tapered hole in the work spindle and the taper nose of the wheel spindle;

(5) parallelism of the work spindle and footstock spindle axes to the direction of table travel;

(6) equal height above the table of the tapered holes in the work spindle and footstock spindle.

Bearing contact is checked by means of special measuring blades—thickness gauges. The contact is considered satisfactory if a blade 0.03 mm thick cannot be inserted between the contacting faces of the table and base ways.

Horizontal position in the longitudinal and transverse directions, as well as straightness of the ways, is checked with a spirit level. Lack of straightness of the base ways must not exceed 0.02 mm per 1,000 mm of table length. The maximum permissible waviness is ± 0.01 mm.

The axial runout of the tapered hole in the work spindle and of the taper nose on the wheel spindle is checked by means of a dial indicator. The maximum permissible runout is 0.01 mm.

Parallelism of the work spindle with the direction of table travel is checked by means of a cylindrical test mandrel, approximately 300 mm in length, having a tapered shank which is inserted with a tight fit into the spindle hole, and a dial indicator. The dial indicator is mounted on the wheelhead in such a way that the contact point touches the top and, subsequently, the side of the mandrel. When the table is traversed, the indicator hand must not deviate by more than 0.01 mm along the entire length of the mandrel.

The coincidence in height between the headstock and footstock centres is checked by means of a special test mandrel with centre holes, which is set up between the centres and tested for parallelism with the table by means of a dial indicator.

Apart from the characteristics enumerated, static control also includes certain other tests, which are carried out by the same methods, using the same tools.

Testing the grinding machine in operation (performance test) consists in grinding a test specimen which is afterwards carefully checked for out-of-roundness, straightness and for the finish of the ground surface.

10-14. GRINDER MAINTENANCE RULES

The operating accuracy of a machine tool, its output, as well as its service life, largely depend upon correct maintenance.

Before commencing operation, all oil must be wiped off the table and other parts of the machine which are not coated with a protective paint. At the end of operation, these surfaces must be wiped clean and coated again with a thin layer of oil.

When mounting the headstock and footstock, the bearing surfaces must be thoroughly wiped, and all dents and burrs must be carefully removed by scraping. Sight oil gauges are checked to see whether there is sufficient oil or lubricating mixture. Lubricant is then applied to all the lubricators and oil holes.

In setting up the swivel table to a given angle, the screws must be locked when the table is in the final position.

To prevent slipping of the pulleys, the tension of all belts must be checked and, where necessary, adjustments must be made.

During operation, the temperature of the wheel spindle bearings must be watched. The bearings must not heat up beyond 50 or 60°C. The reason for heating may be excessive tightness of the bearings, their inadequate lubrication, or incorrectly selected grinding speeds.

Vibration of the machine units must be avoided. The cause of vibration may be poor balancing of the grinding wheel, excessive clearance in the wheel spindle bearings, or belt troubles.

CHAPTER
11

Grinding practice

11-1. THE MANUFACTURING PROCESS

Workpieces to be ground undergo preliminary processing in blank preparation and machine shops (forging, turning, milling, heat treatment, etc.). The type of machining to be applied is determined by the manufacturing process.

The *manufacturing process*, as we have called the sequence of machining operations, is the sum-total of all actions required to change the shape, dimensions, and physical properties of the blank or stock, beginning with the blank and ending with the finished part.

Elements of the Manufacturing Process. The basic subdivision of the manufacturing process or machining cycle is the operation.

An *operation* is a completed stage of a manufacturing process for machining a single part (or group of parts) performed at one workplace and including all the actions of the worker and machine up to the point where the same machining procedure is repeated for the next part in the same lot. The operation is the basic element in terms of which production costs according to a manufacturing process are calculated. It may be carried out in one or several settings of the workpiece in the machine tool.

As an operation is being performed, one or several cutting conditions may change. The tools or the surface being machined, or the speed, feed or depth of cut may be changed. In such a case, the operation will consist of several elements.

An *operation element* is a part of an operation in which the work surface, cutting tool, and speed and feed remain unchanged.

In machining a surface, it may be necessary to remove several layers of stock without changing the tool or the

speed and feed. In such a case, the operation element will consist of several passes, or cuts.

A *pass* is a part of an operation element, associated with the removal of one layer of stock without changing the tool or the cutting conditions.

Allowances. The machining allowance is the thickness of the layer of stock which is to be removed from a blank in order to obtain the finished part. The total allowance is divided into operational allowances, i.e., the stock removed in the separate operations. Each type of machining requires a definite allowance which also depends on the size of the work (Table 13).

Table 13

Operational Allowances in Grinding Shafts

Type of work	Ranges of shaft lengths, mm		
Plain, unhardened	Up to 800	800 to 1,200	1,200 to 2,000
Stepped, unhardened	Up to 400	400 to 800	800 to 1,500
Hardened	Up to 200	200 to 500	Over 500
For centreless grinding	Up to 200	Over 200	—
Diameter ranges, mm:	Allowance on the diameter, mm		
Up to 10	0.25	0.30	—
From 10 to 18	0.30	0.35	0.45
From 18 to 30	0.35	0.40	0.55
From 30 to 50	0.40	0.50	0.65
From 50 to 80	0.50	0.60	0.75
From 80 to 120	0.60	0.70	0.85
From 120 to 180	0.65	0.80	1.00
From 180 to 260	—	0.90	1.10

For instance, the allowance for the grinding of a shaft 30 mm in diameter and 200 mm long after rough machining in the preceding operation is assigned as 0.35 to 0.45 mm on the diameter.

For the same example, the grinding allowance after more accurate semifinish machining is reduced to approximately 0.3 to 0.35 mm on the diameter. The successive removal of the stock by grinding is usually distributed in such a way that 0.9 to 0.8% of the allowance is removed by rough grinding, and the remainder by finish grinding.

Location Surfaces. Surfaces which are used to set up the work for machining, relative to the cutting tool in the machine, are called *location datum surfaces*, or simply *location surfaces*. Thus, when a shaft is ground between centres, the centre holes at the ends of the shaft serve as location surfaces. The location surface of the inner ring of a ball bearing which is to be ground on a mandrel is its bore into which the mandrel is inserted.

Location surfaces can be classified as primary and auxiliary.

Primary location surfaces are used both for setting up the workpieces during machining, as well as for locating them in an assembly with other components. An example of a primary locating surface is the bore of a ball bearing ring.

Auxiliary location surfaces are those which are used only for setting up the work for machining, but which do not mate with other components when assembled. An example of auxiliary location surfaces is the centre holes of a shaft.

The choice of a location surface is important. The best solution of this problem is attained when the same selected location surface is used for all operations, including inspection.

Compulsory Observance of the Manufacturing Process. The established and approved manufacturing process must, as a rule, be observed in production. Any deviations from established procedure may lead to a lower quality of the manufactured product.

However, often a worker, after long acquaintance with the machining of a particular workpiece, can suggest a useful change in the manufacturing process. In the Soviet Union, the essence of such proposed changes is submitted as a time-and-labour-saving suggestion. Each such suggestion should be considered without delay by competent officials of the plant, and if the suggestion is proved to be useful, it should be accepted and introduced.

Following such a suggestion, the required changes of the manufacturing process should be carried out on a pilot scale, and when the changes are finally introduced, a monetary reward should be made to the author, its value depending on the economy effected.

In the Soviet Union, the initiative of worker-innovators is encouraged in every way, and for the organization of this matter, a special office exists at each plant for worker-inventors; furthermore, a U.S.S.R. Association of Inventors and Innovators has been established.

Process Engineering Documentation. Process engineering documentation includes the *process sheets* and all the documents enumerated in them, namely: sketches and drawings of operations (if these are on separate sheets), drawings of jigs and fixtures, special cutting and measuring tools.

The form and content of the process sheets depend on the scale of production. In piece production, i.e., where one or a few pieces of a particular part are made, only a *routing*, or a *master process sheet* is normally compiled for the machining operations.

Such a sheet contains the sequence of machining operations to be carried out on the workpiece with an indication of the approximate standard time per piece and set-up time.

For lot production, machining operation sheets are drawn up for critical parts, in addition to the routing sheet. The former include the cutting speeds and feeds for all operation elements and the calculated time for all items.

Operation sheets are made out for all workpieces in mass production and for critical parts in large-lot production. All entries in the operation sheets refer only to one operation, and are therefore more detailed. In mass production *tooling layouts* are drawn, in addition, for work which is machined in automatic machine tools.

The routing or master process sheet is the main process record of a machine shop for all types of production, and determines the sequence of operations.

The routing sheet is used chiefly by the foreman and the process engineer. The operator uses mainly the operation, or instruction, sheet. In it he can find the cutting speeds and feeds to which the machine is to be set up, the locating, cutting and measuring tools he requires from the tool crib, as well as the procedure to be followed in each setting and operation element.

11-2. SELECTING THE GRINDING WHEEL

Proper selection of the grinding wheel to suit the job to be done is of vital importance. The wheel must produce the required surface finish between wheel dressing operations, with a maximum removal of metal. Suggestions for wheel selection are given in Table 14.

Abrasive material. The property of the material of the work to be ground is of prime importance in the choice of the abrasive material of the wheel.

For the grinding of materials with a high tensile strength, e.g., carbon, alloy and high-speed steels, annealed malleable iron and ductile bronze, corundum wheels must be used.

For the grinding of hard and brittle materials with a low tensile strength, e.g., grey and chilled cast iron, brass, aluminium, hard alloys, etc., aluminium oxide wheels are used.

Grain size. Coarse-grained wheels are more efficient for roughing operations; finish grinding is done with fine-grained wheels.

For the grinding of cemented carbides, fine-grained wheels are often used even for roughing operations.

Hardness (grade). For grinding soft metals, hard wheels are chosen as a rule, and for grinding hard materials, soft wheels. Softer wheels are used for rigid grinders and workpieces. For higher peripheral speeds, softer wheels are employed. The smaller the area of contact between work and wheel, the harder must be the latter.

Structure. The greater the volume of metal removed per unit of time and the more ductile the material being ground, the more porous must the wheel be. An exception is cemented carbides, for which highly porous wheels are also recommended.

Bond. Vitrified-bonded wheels are most widely used. Approximately 80% of all grinding operations in the engineering industries are carried out by such wheels. Rubber-bonded wheels are used to obtain particularly high-grade finishes and when the wheels used must be very thin.

Resinoid-bonded wheels are used for high peripheral speeds.

Table 14

Wheel Recommendations for Grinding Various Metals and Alloys

Metal to be ground	Type of grinding	Cylindrical grinding			Bond	Form grinding			Bond
		Material	Grain	Hardness		Material	Grain	Hardness	
Unhardened carbon steel	Rough	Э	80-50	C1-C2	K	Э	50	C1-C2	K
	Combined	Э	40	C1-C2	K	Э	40-25	C1-C2	K
	Finish	Э	25	C1-CM2	K	Э	25-16	C1-CM2	K
Hardened carbon steel	Rough	Э	50	C1-C2	K	Э	50	C1-CM2	K
	Combined	Э	40-25	C1-CM2	K	Э	40-25	C1-C2	K
	Finish	Э	25-16	CM1-CM2	K	Э	25-16	CM1-CM2	K
Unhardened high-speed steel	Rough	Э	50-40	C1-CM2	K	Э	50-40	C1-CM2	K
	Combined	Э	40	C1-CM2	K	Э	40	C1-CM2	K
	Finish	Э	25	C1-CM2	K	Э	25	C1-CM2	K
Hardened high-speed steel	Rough	ЭБ	50-40	CM1-CM2	K	ЭБ	50-40	C1-CM2	K
	Combined	Э	40	CM1-CM2	K	Э	25	CM1-CM2	K
	Finish	ЭБ	40-25	CM2-M3	K	ЭБ	25-16	CM2-M3	K
Manganese steel	Rough	Э	50	CT1-C1	K	Э	50	CT1-C1	K
	Combined	Э	40	CT1-C1	K	Э	40	CT1-C1	K
	Finish	Э	25	CT1-C1	K	Э	25	CT1-C1	K

Titanium steel	Rough	Э	50	СТ1-С1	К	Э	50	СТ1-С1	К
	Combined	Э	40	С1-С2	К	Э	40	С1-С2	К
	Finish	Э	25	С1-СМ2	К	Э	25	С1-СМ2	К
Unhardened chromium-nickel steel	Rough	Э	80-50	С1-С2	К	Э	80-50	С1-С2	К
	Combined	Э	40	С1-С2	К	Э	40	С1-С2	К
	Finish	Э	25	С1-СМ2	К	Э	25	С1-СМ2	К
Hardened chromium-nickel steel	Rough	Э	40	С1-С2	К	Э	46	С1-С2	К
	Combined	Э	25	С1-С2	К	Э	60	С2-СМ2	К
	Finish	Э	25-16	С1-СМ2	К	Э	80	С2-СМ2	К
Casehardened chromium-nickel steel	Rough	Э	40	С1-С2	К	Э	46	С1-С2	К
	Combined	Э	25	С1-С2	К	Э	60	С1-С2	К
	Finish	Э	16	С1-СМ2	К	Э	80	СМ2-М3	К
Cemented carbides	Rough	КЧ	25	СМ1-М3	К	КЧ	46	СМ1	К
	Combined	КЗ	25	СМ1-М3	К	КЗ	60	СМ1-С3	К
	Finish	КЗ	16-12	С2-М3	К	КЗ	80-100	М3	К
Cast iron	Rough	КЧ	80-50	СМ1-СМ2	К	—	—	—	К
	Combined	КЧ	50-40	СМ1-СМ2	К	—	—	—	—
	Finish	КЗ	25	СМ1	К	—	—	—	—

11-3. MOUNTING AND BALANCING THE GRINDING WHEEL

The grinding wheel is fixed between the flanges of the wheel sleeve *1* (Fig. 97). It is necessary to see that the wheel fits freely on the sleeve but without excessive clearance. The wheel must make firm contact with the flange faces. The clamping flange is secured by screws *2*. Cardboard

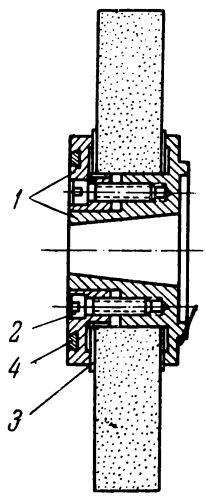


Fig. 97. Clamping the grinding wheel between the flanges of the wheel sleeve

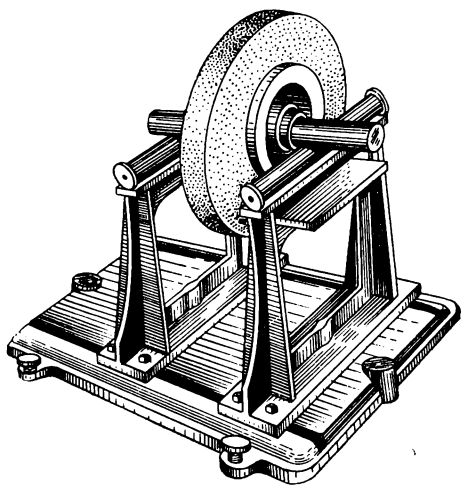


Fig. 98. Wheel balancing stand

washers or blotters *3* are inserted between the wheel and the flanges.

Prior to mounting the sleeve with the clamped wheel on the grinder spindle, the wheel must be balanced, i.e., the common centre of gravity of the wheel and sleeve must be on the axis of revolution.

Balancing is performed on a balancing stand (Fig. 98), consisting of a base and two uprights, to which cylindrical bars are attached. The top of the bars should be in a single, strictly horizontal plane.

The sleeve and wheel are fitted on a special balancing mandrel, whose ends are placed on the bars of the stand.

The wheel rolls along the bars and comes to rest in a position where the centre of gravity of the wheel will be at the bottom.

In order to shift the centre of gravity to the axis of revolution, three weights are used which can be adjusted along annular groove *4* in the left flange (see Fig. 97).

First, the middle weight is fixed in the highest position, and the other two next to it. If the wheel is then pushed, it will roll along the bars and come to rest when the weights are at the bottom. After this, the final balancing operation is performed. For this purpose, the weights are gradually spread apart by equal distances until the wheel is in equilibrium, i.e., until it will come to rest on the bars in any position depending only on the force of the push imparted to it.

The balanced wheel is mounted on the grinder spindle and trued. If after truing the wheel is again out of balance, it must be balanced again.

Truing is shaping or cutting away the wheel to make its face concentric or to alter the shape for grinding special contours. Dressing is done to improve the wheel's cutting action. In this sense it may be regarded as a "sharpening" operation.

In the course of grinding, the diameter of the wheel gradually diminishes due to wear, and it may get out of balance. Therefore, when the diameter has decreased by 50 or 60 mm, the wheel must be rebalanced. In some cases, the unbalance of the wheel is so pronounced that balancing may not be possible. Such wheels must not be used, and are returned to the stores.

11-4. TRUING AND DRESSING THE WHEEL

Grinding with wheel self-sharpening is mainly used for rough grinding operations, in which coarse-grained soft wheels are applied, as for instance in the grinding of cemented carbides.

Self-sharpening results in economy of time as there is no necessity for dressing the wheel; this leads to an increase in productivity. However, the consumption of abrasive increases and the surface finish obtained is inferior. For

these reasons, grinding with wheel self-sharpening is not often used.

In grinding with low infeed, when wheels of hardness CM1-CM2 or above are used, the pressure on the grinding grains does not attain a value at which self-sharpening occurs, and the grinding wheel gradually becomes loaded.

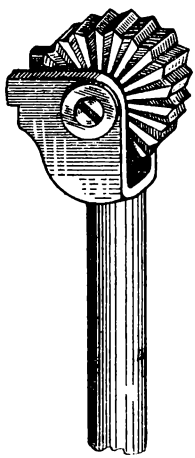


Fig. 99. Star-type dresser for grinding wheels

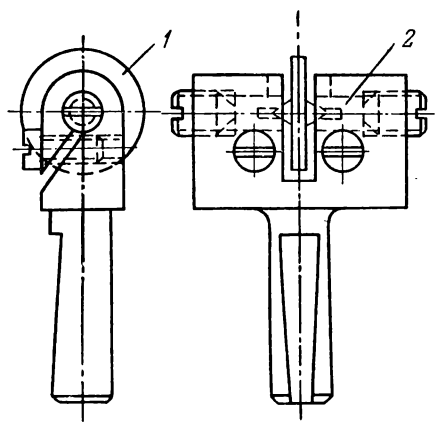


Fig. 100. Holder with a cemented carbide roller

To make it serviceable again, it is dressed by removing a layer 0.05 to 0.2 mm thick from its surface.

Steel star-type dressers and rollers, cemented carbide rollers, abrasive wheels and diamonds are used for truing and dressing.

Steel Star-type Dressers and Rollers. Star-type dressers, consisting of pointed disks or corrugated disks (Fig. 99), loosely mounted on a pin, are used for dressing coarse-grain wheels in snagging grinders.

More often, one-piece cutters in the form of a cylindrical steel roller, with crossed helical grooves cut on the face surface and mounted in a holder on ball bearings, are used for cylindrical grinding machines. In dressing (or truing) with such rollers, the axis of rotation of the latter is set at an angle of 3 to 5° to the axis of wheel rotation.

When the dressing roller meets the surface of the rotating grinding wheel, it commences to revolve at the same speed, but in the opposite direction, and projecting grains on the wheel surface are torn out of the bonding material. Such a method of dressing is called crush dressing. Crush dressing is performed with a longitudinal traverse of 0.5 to 1 mm per sec and an infeed of 0.01 to 0.02 mm per cut. In the longitudinal traverse, the dressing roller must not be advanced beyond the edge of the wheel by more than one half of its (roller) width.

Cemented Carbide Rollers. Since steel rollers wear away very rapidly, cemented carbide rollers are used for crush dressing. Roller *1* (Fig. 100), made of cemented carbide, type BK-6, revolves between sleeves *2*, which are made of the ductile alloy BK-15.

Such a holder is very compact and can be mounted in the socket of a dressing device, in place of a diamond tool. Dressing and truing is carried out with a coolant.

Abrasive Wheel Dressers. Dressing with abrasive wheels by means of grinding or crushing is widely practised.

Dressing wheels are made of black or green silicon carbide. The dressing wheel diameter is usually from one-sixth to one-fourth of the grinding wheel diameter. With respect to hardness, dressing wheels of a hardness value three to four numbers higher than that of the grinding wheel are used; as far as grain size is concerned, they may be similar.

Figure 101 shows a device for wheel dressing by the grinding method, used at the Chelyabinsk Tractor Works. The device is attached to the base of the grinder. The silicon carbide dressing wheel is driven by a special electric motor through gearing.

The headstock drive of the grinder can also be used to rotate the dressing wheel; for this purpose, the latter is fitted on a mandrel to which a driving dog is clamped. It is then set up between the centres in place of the work.

The quality of dressing obtained by the grinding method is somewhat higher than that produced by crush dressing. In dressing by grinding, the grains of the wheel are not only torn out, but are also broken up. This improves the cutting properties of the wheel.

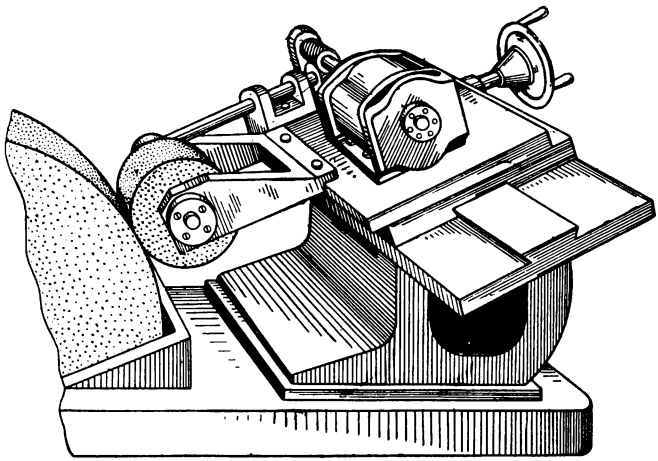


Fig. 101. Device for dressing grinding wheels

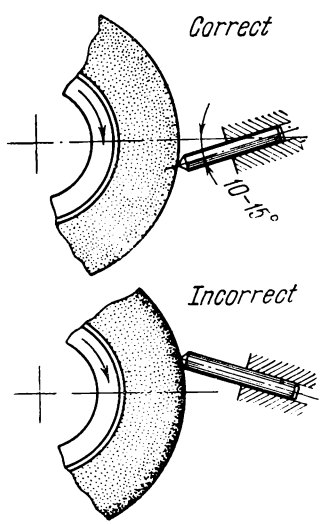


Fig. 102. Position of the diamond in dressing

In practice, however, crush dressing is more frequently used, since dressing by grinding is more costly.

Diamonds. The most satisfactory method of truing and dressing grinding wheels is by the use of diamonds (Fig. 102).

Diamond dressing possesses the advantage that not only are grains removed from the bond, but they are also broken up to a considerable extent, so that the dressed wheel possesses a high cutting quality and ensures a high finish and accuracy of the ground surface.

Industrial diamonds are used for the dressing of wheels. The larger the wheel diameter, and the larger its grains and hardness, the larger must be the size of diamond used for dressing.

For instance, for the dressing of a vitrified-bonded wheel 200 mm in diameter, grain size 46 and hardness CM2, the diamond must be at least 0.3 carat. For a wheel of the same characteristics, but 500 mm in diameter, a diamond of 0.75 carat is required. The diamonds are imbedded or set into a special holder of standard size.

11-5. ACCESSORIES AND ATTACHMENTS

Accessories for Grinding Between Centres. Work is usually mounted between centres in cylindrical grinding. In order to be set up between centres, the work must have centre holes in its end faces.

The *centres* are made solid (Fig. 103*a*) or with a carbide tip (Fig. 103*b*). In grinding work 3 or 4 mm in diameter, reverse centres are used (Fig. 104). In this case, the ends of the workpieces to be ground are made in the form of cones with an included angle of 60°.

A half-centre, one cut away almost to the axis, is used for grinding work of a diameter less than that of the centre. This allows the wheel to clear the centre as it overtravels the work.

In grinding between centres, the headstock (work) spindle does not rotate, and the work being ground is rotated by a driver plate through a *dog* clamped on the end of the work.

The most widely used type of driving dog is shown in Fig. 105. The disadvantage of such dogs is that work of low

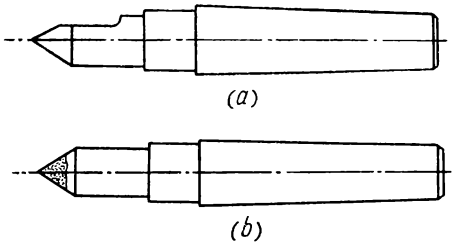


Fig. 103. Centres:
a—ordinary half-centre; b—carbide-tipped centre

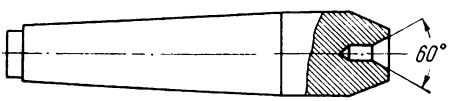


Fig. 104. Reverse centre

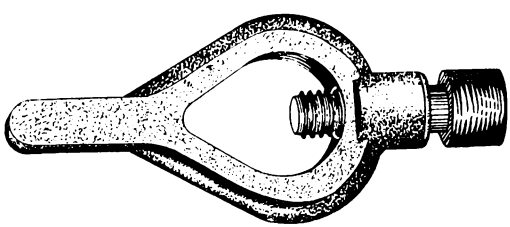


Fig. 105. Driving dog

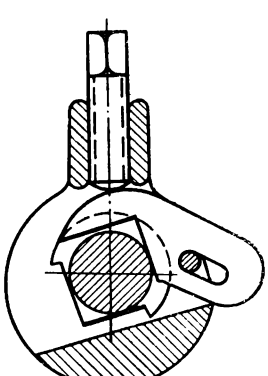


Fig. 106. Universal dog

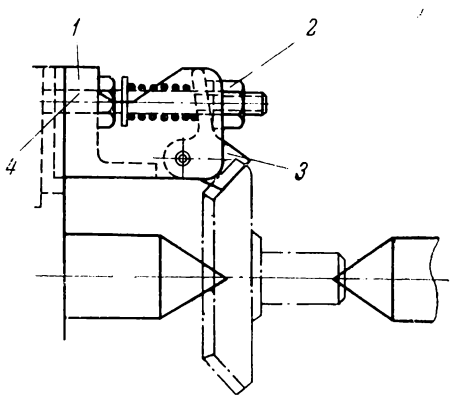


Fig. 107. Driving device

hardness may be dented or marred by the clamping screw. The universal dog (Fig. 106) is free from this shortcoming.

A special *driving device* may be used (Fig. 107) for grinding large lots of pinion shanks. Body *1* of this device is secured to the faceplate of the headstock by means of bolt *4*, and

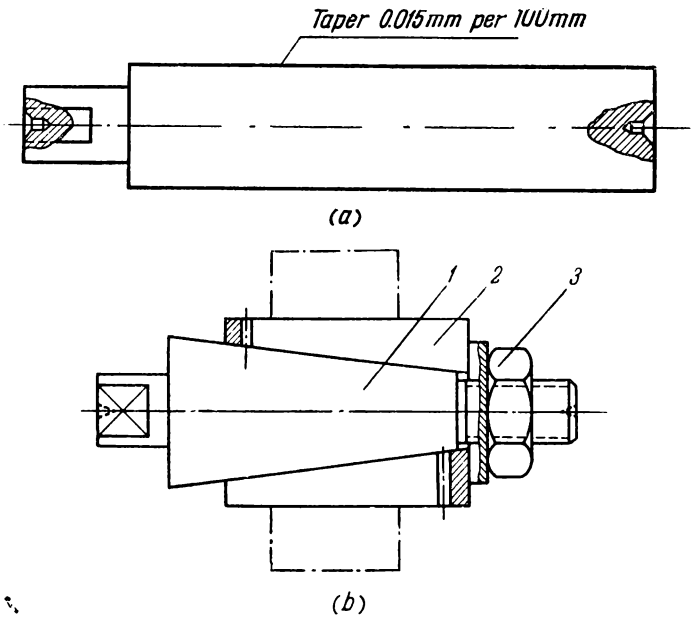


Fig. 108. Mandrels:
a—tapered; *b*—expansion

driving member *3* is set up by means of nut *2* so that when the gear to be ground is mounted between the centres, the driving member enters a tooth space of the gear, and when the faceplate rotates, it drives the gear. The use of such driving devices reduces the handling time, since it excludes the clamping and removal of the dog from each workpiece.

Short workpieces with an accurate hole are ground on long centre mandrels having a slow taper (Fig. 108*a*). The diameter of the mandrel at the smaller end is 0.01 mm less than the nominal diameter of the hole in the work, and the

diameter of the other end of the mandrel is 0.015 mm larger than the hole diameter. The taper of the mandrel must not exceed 0.015 mm per 100 mm. Expansion mandrels (Fig. 108*b*) are used for grinding work for which a wider hole tolerance is specified.

Spring sleeve *2* has 3 to 6 axial slots on each end. On tightening nut *3*, the inner tapered surface of the sleeve

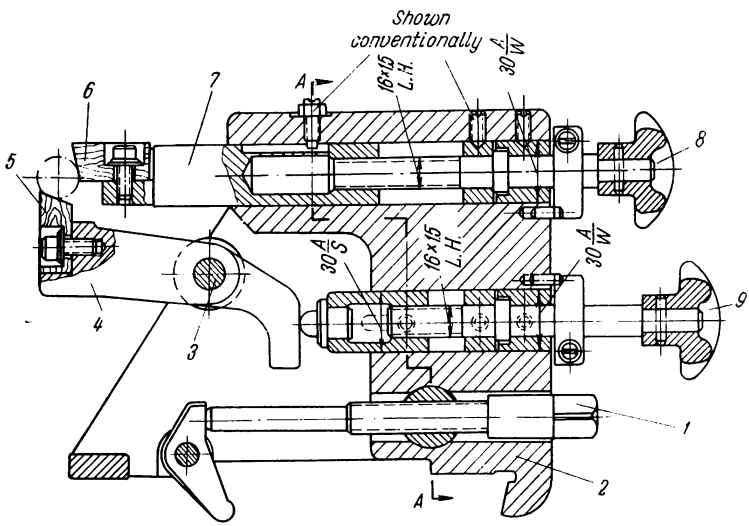


Fig. 109. Steady rest

is moved along the outer taper of body *1* as a result of which the sleeve is expanded and the work is firmly clamped.

Steady Rests. In grinding long work, the latter may be bent under the action of forces arising during grinding (forces P_y and P_z). To preclude such bending, special devices are used, known as steady rests (Fig. 109).

Body *2* of the steady rest is mounted on the table and clamped by screw *1*. The horizontal bearing shoe *6* is attached to sliding holder *7* which is adjusted by screw *8* to suit the work being supported. Lower bearing shoe *5* is attached to rocker arm *4*. When screw *9* is turned, arm *4* rotates on pin *3* and advances lower shoe *5* towards the workpiece.

During grinding, the shoes must be periodically advanced towards the work as the diameter of the latter decreases. Depending on the length-to-diameter ratio of the workpiece, one, two or more steady rests are used.

Chucks. *Four-jaw chucks*, in which the jaws can be moved independently (Fig. 110), are often used for grinding separate workpieces. Each jaw *1* of this chuck can be moved by

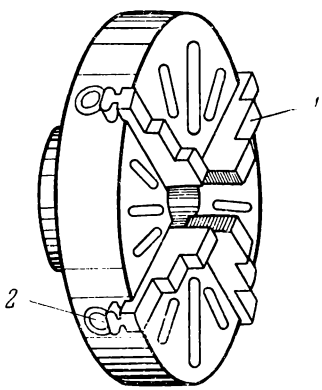


Fig. 110. Four-jaw chuck

means of its screw *2*. Such chucks are used for external or internal grinding of workpieces having nonconcentric surfaces which are to be clamped by the chuck.

The work is set up in the chuck with the aid of a dial indicator.

The *self-centring three-jaw chuck* is used for clamping workpieces on which the external or internal surface to be ground is concentric with the one (location surface) to be clamped. In grinding work in a self-centring chuck, the error in the alignment of the location datum surface and the surface to be ground ranges from 0.05 to 0.25 mm.

The mechanism of the three-jaw self-centring chuck is shown in Fig. 111. The lower surface of disk *1* is an annular bevel gear, meshing with three bevel pinions *2*, spaced at 120° in body *3* of the chuck.

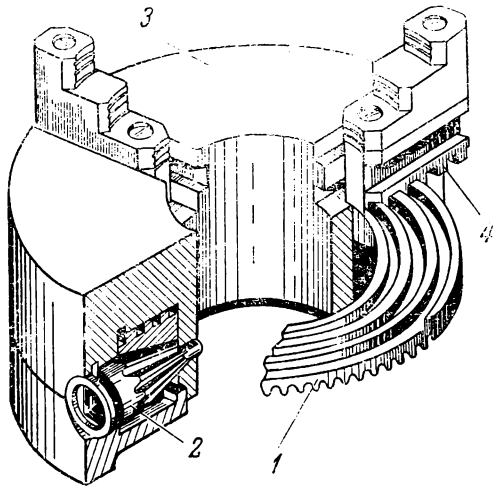


Fig. 111. Three-jaw self-centring chuck

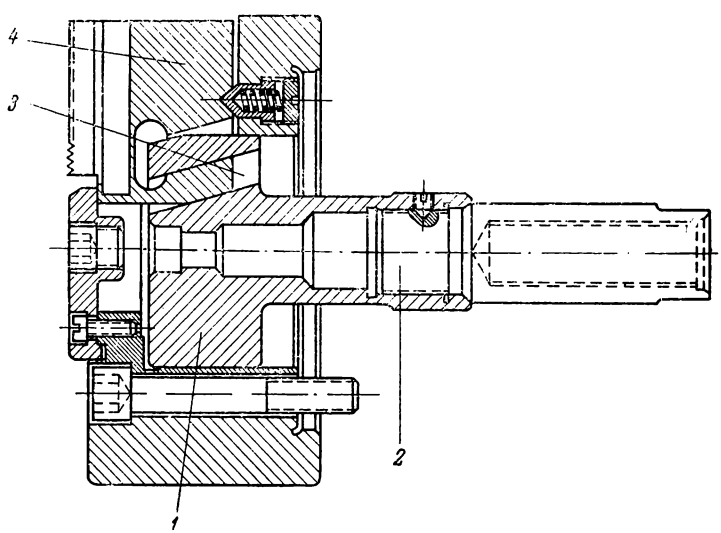


Fig. 112. Three-jaw pneumatic chuck

Rotation of any one of the bevel pinions leads to rotation of disk *1*. A spiral scroll is cut into the upper face of the disk, which engages the teeth on the bottom of jaws *4*. When disk *1* is turned, all three jaws move simultaneously towards, or away from, the centre of the chuck, depending on the direction of revolution of the disk.

A large number of identical workpieces with closer tolerances for the location surface are ground in *three-jaw pneumatic chucks* (Fig. 112). Attached to the right end of draw rod *2* is the piston of a pneumatic cylinder; attached to its left end is sleeve *1*, with three accurately machined grooves *3*. The axis of each groove is at an angle of 15° to the axis of the chuck. Lugs of jaws *4* fit into these grooves. When the rod moves to the right, the jaws move towards the centre, clamping the workpiece.

To release the workpiece, the piston of the pneumatic cylinder is reversed, the draw rod is moved to the left and the jaws are opened.

Pneumatic chucks are more accurate than self-centring chucks, they facilitate the work of the operator and reduce the time spent in clamping and releasing the work.

Jaw chucks are unsuitable for gripping thin-walled work. In such cases, *diaphragm chucks* are used (Fig. 113).

To the face of an elastic diaphragm *a* (Fig. 113*a*), a force P is applied, under the action of which the former deforms and the lugs (jaws) *b*, attached to the face of the diaphragm, spread apart. As a result, the distance B between the jaws increases by the amount c. If now a workpiece of external diameter $D = B + c$ is inserted between the jaws, and the action of force P on the face of the diaphragm is discontinued, the workpiece will be clamped by the forces set up by the deformation of the diaphragm.

Body *2* of the chuck (Fig. 113*b*) is inserted with its tapered shank into the work spindle and secured by a threaded tube. Draw bar *1* passes through the hole of the spindle and tube. At its left end the draw bar is connected to the piston of a pneumatic or hydraulic cylinder.

When compressed air or oil is admitted into the cylinder, the head of the rod is pushed against the face of the diaphragm to retract jaws *3*, which may number from 10 to 20. In this position, the jaws are ground to a diameter exceeding that

of the work to be ground by 0.03 to 0.05 mm. Simultaneously, three rest pins *4*, used for locating the work, are ground. After this the chuck is ready for operation.

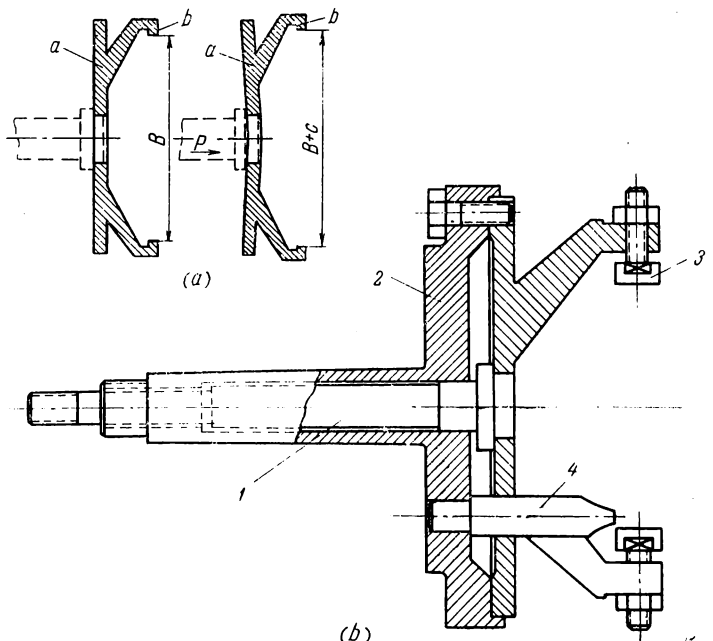


Fig. 113. Diaphragm chuck:
a—principle; *b*—construction

Diaphragm chucks may be used for internal and external grinding.

Attachment for Grinding Cams and Other Out-of-round Surfaces. Special attachments are used for grinding out-of-round external surfaces in cylindrical grinders. One such device, used for grinding shaped die punches, and operating by tracer control, is shown in Fig. 114.

Rigidly fixed on plate *11* is angle *7* to which stop *5* is screwed. The bearing surface of this stop is concentric with the surface of the grinding wheel. A rotating cam (master cam) is held constantly by spring *6* against this

surface of the stop. The cam is rigidly secured to spindle *4* of the device. The spindle rotates in sleeve *2* which is rigidly secured to V-block *3*. Due to the provision of centre mandrel *1*, attached to the other side of the V-block, the latter can rock in the centres, thus enabling the rotating cam to remain in constant contact with stop *5*.

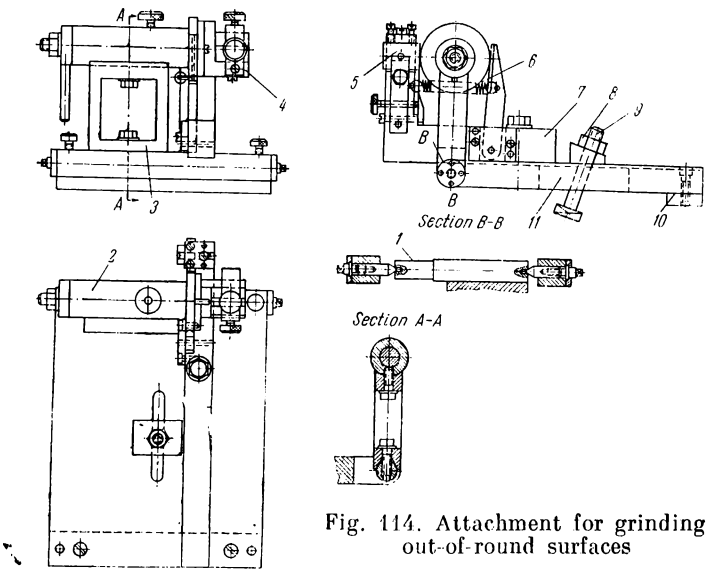


Fig. 114. Attachment for grinding out-of-round surfaces

The work to be ground is mounted in the head of the spindle coaxially with the master cam. When the grinding wheel approaches the rotating workpiece, the latter moves with respect to the cutting surface of the wheel, accurately reproducing the movement of the rotating cam with respect to the stop. The work is considered to be finished when measuring shows that one of its dimensions has reached the size specified in the drawing, i.e., inspection of shaped work ground in this device, as well as the grinding process itself, are carried out in the same way as in the case of cylindrical workpieces.

The device is designed and manufactured for use in a definite grinder. The distance from the lower surface

of plate *11* to the axis of the spindle in the device must correspond to the height of the centres of the grinder within ±0.5 mm. The distance from the lower surface to the centre of the radius on the bearing surface of stop *5* must be equal to that from the spindle axis of the wheelhead to the table surface within ±0.05 mm.

Such devices are mounted on the machine in the following order:

(1) the rectangular head of bolt *9* is inserted into the T-slot of the grinder table;

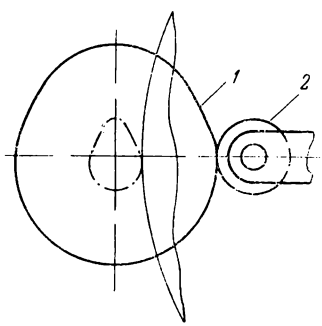


Fig. 115. Principle of tracer grinding with a rotating roll

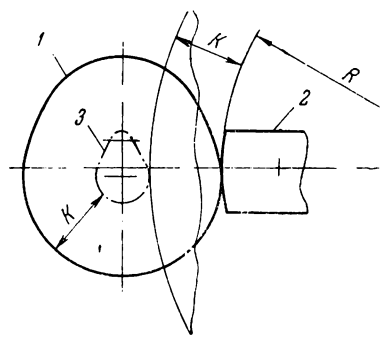


Fig. 116. Principle of tracer grinding with a rigid stop

(2) the lower surface of the plate of the device and the surface of the table are carefully wiped;

(3) the device is pushed forward until strip *10* makes contact with the side of the table. Nut *8* is then drawn up tight.

The profile and calculation of cams used in special tracer-controlled cam grinders are very complex.

This is due to the fact that the diameter of the rotating cam roll *2* (Fig. 115), which serves as a stop for the rotating master cam *1*, is considerably smaller than that of the grinding wheel. A rotating stop (roll) for the cam is employed in cam grinders used in mass production to reduce the wear of the cam and the stop to a minimum.

In the device described below, stop *2* for the rotating cam *1* (Fig. 116) is fixed and its working section is in the form of an arc, whose radius is somewhat larger than that of the grinding wheel.

In this case, the master cam has a much simpler profile. All radii of cam shape 3 of the work to be ground are read off the drawing and increased by the same amount K (e.g., $K = 30$ mm), and from the centres of these radii, the corresponding arcs are described until they merge. The profile of the master cam is thus obtained.

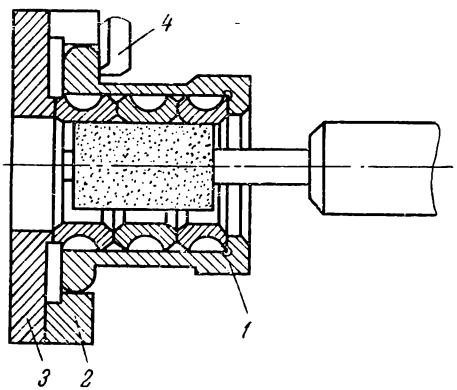


Fig. 117. Device for grinding the holes of three bearing rings in one setting

The value chosen for K must be taken into consideration in selecting the grinding wheel diameter. Theoretically, the wheel diameter is given by the formula

$$D = 2(R - K)$$

where R is the radius of the stop.

In practice, a deviation of the diameter of the grinding wheel from the calculated value by up to $\pm$ 20 mm has very little effect on the accuracy of the ground profile.

If a grinding wheel is to be used whose size differs considerably from that calculated, the stop must be replaced by one having a radius

$$R = \frac{D}{2} + K + 20$$

where 20 mm is the allowance for dressing the wheel in the course of grinding.

Devices are also used in grinding machines which reduce the handling time and are designed for the grinding of large lots of identical workpieces.

One such device for grinding the bores of three ball-bearing rings in one setting is shown in Fig. 117. Sleeve *1* with the rings to be ground is inserted in guide ring *2* and forced against the face of flange *3* by jaws *4*. Whilst they are being ground, the operator puts three new rings into a spare sleeve.

11-6. PREPARING AND SETTING UP THE MACHINE FOR GRINDING

Setting-up operations depend upon the construction of the grinder and the nature of the work.

The main steps in setting up the machine for grinding between the centres, the method most widely used for grinding external cylindrical surfaces, consist of the following:

1. The centres are installed. The footstock centre must project from the footstock spindle by 1.5 *H* (where *H* is the width of the wheel). For grinding work of small diameter, the side of the footstock centre facing the wheel is cut away over the same length (1.5 *H*) so that the wheel clears the centre.
2. A driver plate is mounted on the work in grinding with a dead (stationary) headstock centre.
3. The swivelling table is set to the zero position.
4. The lateral pressure on the work is adjusted by means of the footstock centre. The lighter and thinner the workpiece, the lower must be the pressure. Excessive pressure results in rapid wear of the centres, whereas with too low a pressure the work may be thrown out from between the centres.
5. Steady rests are installed for grinding long workpieces.
6. Coolant flow is regulated and checked.
7. The wheel is trued. If it is new, it must be accurately balanced.
8. The work speed and table traverse are selected according to the process sheet.
9. The table reversing dogs are set up.
10. The workpiece is mounted between the centres. The centre holes (Fig. 118) in the workpiece must be accu-

rately drilled. Deviations in the taper angle and out-of-roundness of the centre hole are inadmissible. Similar requirements are made to the headstock and footstock centres.

Dogs for driving the workpieces are selected to suit the diameter of the workpieces. Centre mandrels are used for grinding hollow work.

11. The mechanism for automatic infeed disengagement is adjusted. For this purpose, the work is set up and

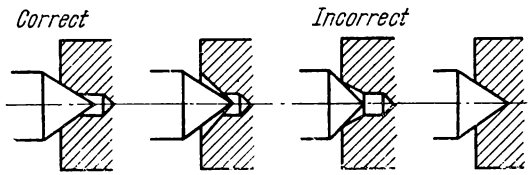


Fig. 118. Centre holes

the machine started. By means of the infeed handwheel, the grinding wheel is advanced to the work until sparking just begins. In this position, the dial of the handwheel is released, without moving the latter, and the number of divisions the pilot handwheel must be turned in order to remove the entire allowance from the work is counted off on the dial from zero to the right. A chalk mark is made at the required division. The dial is then set so that the chalk-marked graduation line coincides with the index line of the infeed mechanism and is secured in this position.

When the entire allowance has been ground off, and the zero line of the dial reaches the index line on the housing, a special cam attached to the dial disengages the automatic infeed. After sparking out, the wheel is retracted from the work. The workpiece is then removed and inspected. If it is satisfactory, the grinder is considered to be correctly set up.

11-7. GRINDING EXTERNAL CYLINDRICAL SURFACES

Methods of Grinding. Grinding operations consist of rough and finish grinding. In rough grinding, 80 to 90% of the allowance is removed within a short time. Therefore coarse-grained hard wheels are used for such grinding. The grinding

feeds are higher: traverse speed is 0.8 to 0.9 of the wheel width, infeed is 0.01 to 0.08 mm per revolution of the work. The requirements for surface finish are not very high, but burns and grinding cracks are inadmissible.

After rough grinding, the remaining allowance is removed by finer-grained wheels of lower hardness, using lower feeds. The rate of traverse is from 0.25 to 0.3 of the wheel width, and the infeed, from 0.002 to 0.01 mm per revolution.

After disengaging the infeed, the grinding wheel is retracted from the work when sparking ceases (after sparking

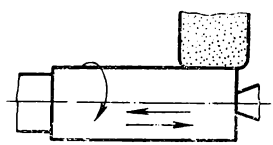


Fig. 119. Traverse grinding

out) when the table is in the extreme position. The longitudinal traverse of the table is disengaged after retracting the wheel.

In external cylindrical grinding, the following methods of grinding are used:

(1) traverse grinding;
(2) full-depth grinding;
(3) plunge-cut grinding;
(4) combined traverse and plunge-cut grinding.

Traverse Grinding. In this method of grinding (Fig. 119), the table with the rotating work travels in the longitudinal direction until it meets a dog which reverses its travel. At the instant of reversal, the table speed is zero; at that very moment, infeed, i.e., crosswise movement of the wheel towards the work, is accomplished. Infeed can be effected either at the end of each table stroke or only when the work is in the extreme right-hand position, i.e., after the table has completed a double stroke (back and forth).

The dog for reversing longitudinal travel of the table must be set so that the wheel does not run completely off the work, since otherwise its ends will be rounded off. However, if the wheel does not overtravel sufficiently, the size at the ends of the work will be larger than that

at the middle. If the dogs are correctly adjusted, table reversal will occur when the wheel has passed beyond the edge of the workpiece by one-third of the wheel width.

The traverse grinding method is used mainly for grinding long work.

Full-depth Grinding. Full-depth, or single-pass, grinding is a process in which the entire allowance, usually 0.1 to 0.3 mm on each side, is removed in one pass at a low rate of traverse (Fig. 120). The traverse rate should be as high

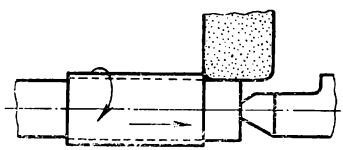


Fig. 120. Full-depth grinding

as possible, provided that no sparking occurs on disengaging table traverse at any moment and on withdrawing the table.

Full-depth grinding is performed only in one direction. After each workpiece is ground, the table is returned to its initial position to set up the next workpiece, whilst the position of the wheelhead remains unaltered.

This method ensures uniform size of the ground workpieces in a lot and enables sampling measurements to be made. The conditions of cutting in this method are considerably more favourable and the workpieces are heated less than in traverse grinding. Full-depth grinding is currently widely used and innovator grinders still continue to improve it.

The devices usually recommended to true the entering taper on the wheel are quite complex in construction and much time is lost in installing and removing them, as well as in the truing process.

An innovator grinder, G. Kochetkov, has suggested a different method of truing the taper. He grinds the first few workpieces by the ordinary traverse method, using an infeed of 0.1 to 0.15 mm per double stroke and a traverse rate of 0.1 of the width of the wheel per revolution of the work. After grinding two or three workpieces, a taper is formed on the wheel and the remaining work can then be ground by the full-depth method.

In full-depth grinding, rough and finish grinding is combined in a single operation. The degree of surface finish depends on the condition of the cylindrical portion of the wheel. During grinding it gradually wears away, and when its width reaches 6 to 8 mm, a spiral band appears on the ground surface, which indicates that the wheel must be dressed.

If the grinding allowance exceeds 0.3 mm on each side, then for full-depth grinding the wheel must be trued with a step (Fig. 121) or with a long taper.

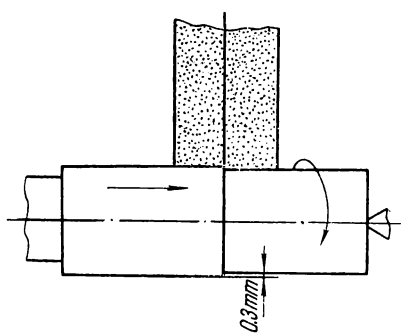


Fig. 121. Step-trued wheel used in full-depth grinding

If a stepped wheel is used, the difference between the diameters of the wheel steps is from 0.4 to 0.5 mm. In long-taper wheels, the truing angle is between 1°30′ and 1°45′.

In special cases, a double wheel may be used, in which the first wheel, for roughing, is more coarse-grained and harder than the second. To facilitate dressing of the first wheel, a spacer 5 or 6 mm thick is placed between the wheels.

In full-depth grinding, the wheel must completely overtravel the workpiece. However, in certain cases work can be ground by this method, in which the diameter to be ground is adjacent to a shoulder. In such cases, the wheel is advanced to the shoulder until sparking just begins, and then, by wheel infeed, the work is ground to final size, the table remaining stationary. After sparking out, table traverse is engaged away from the shoulder, until the wheel has completely overtravelled the work.

Prior to commencing grinding of the next workpiece, the wheel must be retracted. Thus, in such a case, a combination of full-depth and plunge-cut grinding is achieved.

Plunge-cut Grinding. Plunge-cut grinding is a method in which the work is not traversed longitudinally and grinding proceeds simultaneously along the entire length of the work. The width of the wheel must exceed the length of the work by 1 to 1.5 mm.

Infeed is continuous, and is equal to 0.005 to 0.06 mm per revolution of the work in rough grinding, and 0.001 to 0.004 mm in finish grinding.

Plunge-cut grinding yields a higher output. Moreover, profiled as well as stepped work can be ground by this method.

The usual working cycle in plunge-cut grinding includes roughing at an infeed of 0.6 to 2.0 mm per min, in which 90 to 95% of the allowance is removed. A few divisions before the zero mark on the dial, finish grinding commences, in which the infeed is reduced to 0.1-0.4 mm per min and the remaining allowance is removed. Then the infeed is disengaged but grinding continues until the wheel sparks out. Then the wheel is withdrawn and a new workpiece is set up.

Innovator grinders have introduced changes into the above plunge-cut grinding process. G. Kochetkov does not reduce the rate of infeed in finish grinding and does without sparking out. To compensate for deformation in the machine-workpiece-grinding wheel complex, he feeds in the wheel 0.03 mm more than the value noted on the dial, and retracts the wheel immediately with practically no sparking out whatsoever.

Such a method of grinding gives a considerable gain in productivity, and if skilfully used, ensures the required quality of finish.

As the wheel becomes dulled, the rate of infeed is reduced from the upper to the lower limit. When the wheel no longer grinds properly (drastic increase in noise, intermittent sparking, deterioration of surface finish, etc.), grinding is interrupted and the wheel is dressed.

Owing to the considerable width of the zone of contact between the wheel and the work in plunge-cut grinding, a large quantity of heat is generated.

Combined Traverse and Plunge-cut Grinding. This method is used for grinding long workpieces.

In this method, grinding is effected by successive plunge cuts (Fig. 122), leaving an allowance of 0.04 to 0.07 mm. In each cut the rear edge of the wheel must overlap 2 to 3 mm on the previously ground surface.

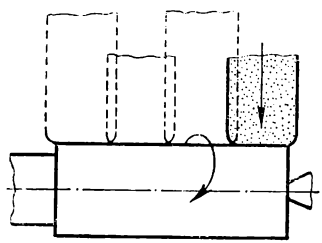


Fig. 122. Combined traverse and plunge-cut grinding

When the work has thus been ground over the entire length, the wheel is dressed, and the work is then ground to final size by several passes at a rate of traverse of 0.9 of the wheel width.

11-8. FACE GRINDING

In mass production, the end faces of workpieces are ground in special face-grinding machines. For instance, the end faces of cylindrical rollers for roller bearings are ground in one pass by two wheels. Each wheel is mounted on a separate wheelhead, and the relative position of these wheelheads determines the length of the ground rollers.

Such a method for grinding faces ensures a high output, but requires special machine tools. For this reason, its application is economically justified only for the grinding of large quantities of parts.

In small-lot production, as well as for grinding faces of shoulders, face grinding is carried out in conventional cylindrical grinders.

Grinding with the Side of the Wheel. Shoulders are usually ground by this method (Fig. 123). The side of the wheel is trued with an undercut (hollow trued), and cutting

is effected only by the grains of the extreme edge of the wheel.

Apart from the fact that the number of grains participating in cutting is limited, the conditions of operation in face grinding are made difficult, since the contact surface between the wheel and the work is large, and each grain cuts the surface being ground along the entire length of this contact.

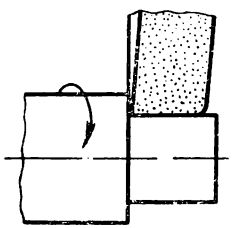


Fig. 123. Grinding with the side of the wheel

The volume of metal removed by each grain is thus considerably larger than in grinding with the periphery of the wheel.

As a result, intense heat generation occurs in the cutting zone, and in order to avoid burns and grinding cracks, grinding must be carried out with very small feeds and ample cooling.

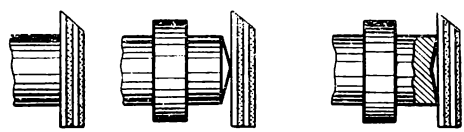
Shoulders are ground with the side of the wheel in the following order. After grinding the cylindrical surface, adjacent to the shoulder, to its final size, the grinding wheel is withdrawn 0.3 to 0.05 mm, and the side of the wheel is advanced by hand to the shoulder being ground. Then, when sparking begins, the shoulder is ground with careful intermittent manipulation of the longitudinal traverse handwheel.

Sparking and the noise developed in the cutting zone give an experienced grinder a good idea of the progress of grinding. In many cases, face grinding is performed only to clean up, i.e., until all traces of the preceding operation have been removed.

The ground faces are inspected for flatness by means of a straight edge (Fig. 124).

The setting of the wheelhead is very important in order to obtain an accurate face. The axis of the wheel spindle must be strictly parallel to the direction of the longitudinal traverse of the table.

The wheelhead is usually set up according to the circular scale; for grinding cylindrical surfaces, this is acceptable, since after truing, the face of the wheel is parallel to table travel. However, in grinding with the side of the wheel.



(*a*) (*b*) (*c*)

Fig. 124. Checking end faces with a straight edge:
a—correct face; *b*—convex face; *c*—concave face

the error made in setting the wheelhead has a noticeable effect on the quality of the face on the work. If the ground face is convex, this means that the axis of the wheel spindle is not parallel with the direction of table travel, but is at some angle to it, the apex of which is directed towards the headstock. Conversely, concavity of a ground face indicates that the apex of the angle formed between the spindle axis and the table ways faces the footstock.

For grinding two faces of a workpiece, the distance between which must be maintained within given tolerances, setups are used with a dial indicator, fixed to the base of the machine, and an accurate strip. The latter is secured in the longitudinal T-slot of the table in the same way as the reversing dogs. The application of this setup is demonstrated in the following two examples.

Example 1. For the mandrel shown in Fig. 125*a*, the dimension 80 $\pm$ 0.015 mm is to be maintained. The grinding allowance is 0.5 mm.

The wheel is advanced to the first shoulder until sparking begins and the strip is advanced to the dial indicator so that its hand makes one revolution. The strip is then fixed in this position. Having set the indicator scale to zero, the shoulder is ground until the indicator hand reaches the 20th division.

This means that 0.2 mm of stock has been removed. Feed is then discontinued, and after sparking out, the grinding of the first shoulder can be regarded as completed. Then the second shoulder is ground to clean up in the same manner, and a measurement is made.

Let us assume that the reading is 80.25 mm. The dial indicator scale is then set to zero and the second shoulder

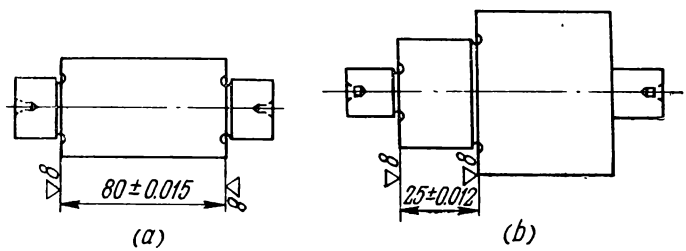


Fig. 125. Grinding mandrel shoulders:
a—on both sides; *b*—on one side

is ground until the hand reaches the 25th division. Then the feed is disengaged. Grinding continues until the wheel sparks out.

Example 2. In the mandrel shown in Fig. 125*b*, a distance of $25\frac{1}{2} \pm 0.012$ mm must be maintained between the shoulders.

First, both shoulders are ground to clean up and measured. Let us assume that the reading is 25.3 mm. The wheel is then advanced to the smaller shoulder until sparking just begins. The dial indicator hand is now set to zero and the shoulder is ground until the hand reaches the 30th division.

If, after grinding both faces to clean up, the size is 24.7 mm, instead of 25.3 mm, then the larger shoulder is ground in the same manner.

In some cases, face grinding is performed simultaneously with the grinding of the adjacent diameter by means of a specially trued grinding wheel (Fig. 126). In this case, the axis of the wheel spindle is set at an angle to the axis of the work to be ground (this angle is most frequently 45°).

The infeed is, as usual, perpendicular to the axis of revolution of the grinding wheel. Such a method of face grinding

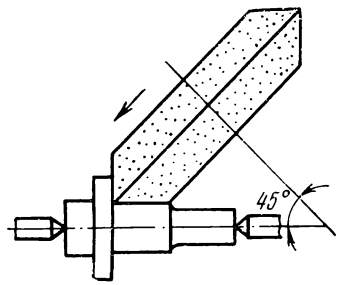


Fig. 126. Grinding the diameter and shoulders simultaneously

is quicker, and if carried out correctly, ensures the required accuracy of the ground work.

11-9. GRINDING EXTERNAL TAPERED SURFACES

Workpieces with tapered surfaces are often encountered. The spindle nose of each lathe, milling or drilling machine has a tapered socket for installing centres or cutting tools with a corresponding tapered shank. The sizes of the tapered sockets of the spindles, as also those of the tapered shanks of the tools and centres, are standardized.

Table 15

Morse Tapers

No. of taper	D	d	l	Taper k	Angle of taper α
0	9.045	6.453	49.8	0.0521	1°29′27″
1	12.065	9.396	53.5	0.0499	1°25′43″
2	17.780	14.583	64.0	0.0500	1°25′50″
3	23.285	19.784	80.5	0.0502	1°26′16″
4	31.267	25.933	102.7	0.0509	1°29′16″
5	44.399	37.573	129.7	0.0526	1°30′26″

Table 15 gives the taper sizes of the universally accepted Morse taper system from No. 0 to No. 5. In addition to the

length of the tapered shank and its major and minor diameters, the values of taper k and the angle of taper α are given for each Morse taper.

These parameters are characteristic not only of Morse tapers, but also of any other taper system. In Fig. 127, the

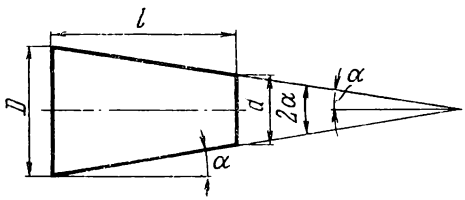


Fig. 127. Elements of a taper

section of a tapered plug and all elements characteristic of a taper surface are shown.

The amount of taper k is the ratio of the difference in the larger and smaller diameters of the taper to its length. Thus

$$k = \frac{D-d}{l}$$

Let us assume that $D = 110$ mm, $d = 80$ mm and $l = 150$ mm, then

$$k = \frac{110-80}{150} = 0.2$$

If the value of the amount of taper is halved, the taper from the centre line n is obtained, i.e.

$$n = \frac{k}{2} = \frac{D-d}{2l}$$

For the values given above, the taper from the centre line is

$$n = \frac{110-80}{2 \times 150} = 0.1$$

The taper from the centre line is equal in value to the tangent of the angle of taper α (see Fig. 127)

$$\tan \alpha = n = \frac{D-d}{2l}$$

The angle of taper for the dimensions given above will be

$$\tan \alpha = n = 0.1$$

$$\alpha = 5°43'$$

Twice the angle of taper is called the included angle of the taper or the apex angle of the cone.

Apart from Morse tapers, metric tapers are used in the U.S.S.R. in engineering, as well as the tapers 1 : 100, 1 : 50, 1 : 30 and 1 : 10.

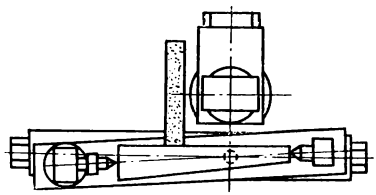


Fig. 128. Grinding tapered surfaces by swivelling the table

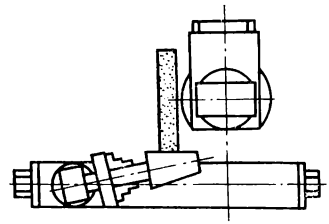


Fig. 129. Grinding tapered surfaces by swivelling the headstock

Methods of Grinding. Depending on the angle of taper of the work, various methods are used for grinding tapered surfaces. Work having a taper angle not exceeding 15° are ground by *swivelling the table* (Fig. 128).

The upper swivel table of the machine is turned through an angle equal to the angle of taper of the work. With this table setting, an element of the taper facing the grinding wheel is parallel to table travel. Rough table swivel settings are made to the scale on the machine.

After the first few passes, the angle of taper obtained is checked, and if it deviates from that specified in the drawing, the setting of the table is corrected. If subsequent checking shows the actual taper angle to be within the required limits, the swivel table is secured in this position.

Further grinding is carried out by longitudinal traverse. Infeed is effected by movement of the wheelhead in the same way as in grinding cylindrical surfaces.

Work having a taper angle over 15° is ground by *swivelling the headstock* (Fig. 129). The work is mounted and held in a chuck. When the swivel table is set to its zero position,

the headstock is released and swivelled to a scale, to the angle of taper to be ground, and finally secured in this position.

Then the tapered surface of the work is ground in several passes, and the actual taper angle is checked. If necessary,

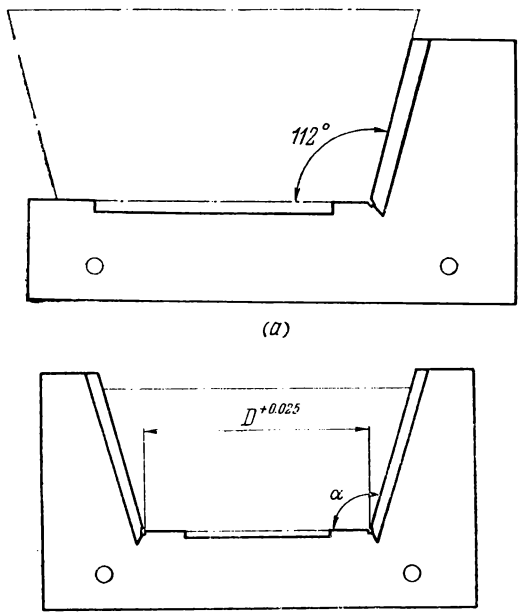


Fig. 130. Gauges:
a—for checking the angle of taper; *b*—for checking the angle and smaller diameter of taper

the angle is corrected by swivelling the table. When the required angle is obtained, the table is finally secured and the workpiece is ground to size.

The workpieces are ground by longitudinal traverse. Infeed is effected by moving the wheelhead. Work with short tapered surfaces is often ground by plunge-cut grinding (e.g., the inner races of tapered roller bearings).

Checking the Accuracy of Tapered Work. In practice, various methods of inspecting tapered workpieces are used.

The angle of taper of the surface can be checked with a bevel protractor, or in the case of a large number of identical parts, by a special gauge (Fig. 130*a*). Testing with this gauge does not guarantee accuracy of the diameter of the ground work.

In cases when the smaller diameter of a tapered surface is specified within narrow tolerance limits, a gauge is used

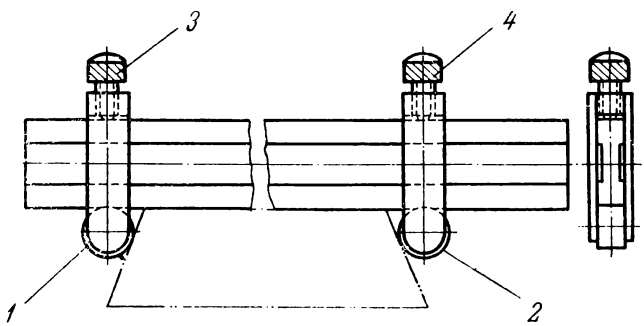


Fig. 131. Roller gauge for checking tapered surfaces

which checks the taper angle and the diameter simultaneously (Fig. 130*b*).

In grinding work with a small taper angle, e.g., centres, tapered shanks of drills and end mills, special checking gauges are used for testing the angle of taper and the diameter.

In grinding separate pieces, the smaller diameter of the ground taper is checked by means of a universal roller gauge (Fig. 131). Rollers *1* and *2* are of the same diameter within very close tolerance limits. The distance between the rollers depends on the magnitude of the smaller diameter of the taper and on its angle of taper, as well as on the diameter of the rollers. This distance is determined by the formula

$$H = d\left[\cot\left(45° - \frac{\alpha}{2}\right) - 1\right] + D$$

where d = roller diameter
D = smaller diameter of the taper
α = angle of taper.

According to the calculated dimension of H, a set of gauge blocks is assembled and inserted between the rollers. The position of the rollers thus obtained is then fixed by screws *4* and *3*.

Example. The distance between the rollers for testing the smaller diameter of the ground taper is to be calculated from the following data: $d=10$ mm, $\alpha=30°$, and $D=80$ mm.

Solution.

$$H = d\left[\cot\left(45°-\frac{\alpha}{2}\right)-1\right]+D=10\left[\cot\left(45°-\frac{30°}{2}\right)-1\right]+80=87.32 \text{ mm}$$

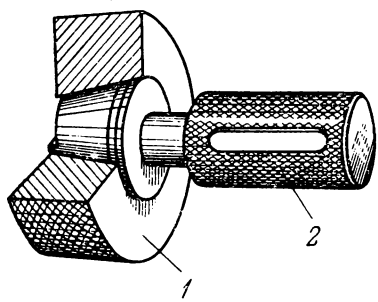


Fig. 132. Gauges for checking tapered surfaces:
1—ring gauge; *2*—plug gauge

Checking the taper angle by means of a bevel protractor does not give very accurate results. The use of taper plug and ring gauges (Fig. 132) yields good results only for small taper angles.

Great accuracy in taper angle measurements is attained by the use of a special *device with a sine bar* (Fig. 133). Centre stocks *5* and *6* are mounted on hinged sine bar *1* which is in the form of a plate. The stocks are adjusted and clamped in position according to the length of the work. On the lower surface of sine bar *1* is pin *4* and cylindrical plug *2*, the distance between which is maintained with great accuracy, and (in the given case) is 250 mm. Pin *4* acts as a hinge for connecting sine bar *1* and main plate *3*.

To test the taper angle, e.g., with an included angle of 32°, the workpiece is mounted in the device as shown in Fig. 133. From a trigonometric table, the sine of the angle

16° (the angle of taper being measured) is found, which is 0.27564. Taking into consideration that the distance between the sine and plug of the device $l = 250$ mm, the height H of the set of gauge blocks which must be placed under the plug *2* of the sine bar can be found: $H = 0.27564 \times 250 = 68.91$ mm.

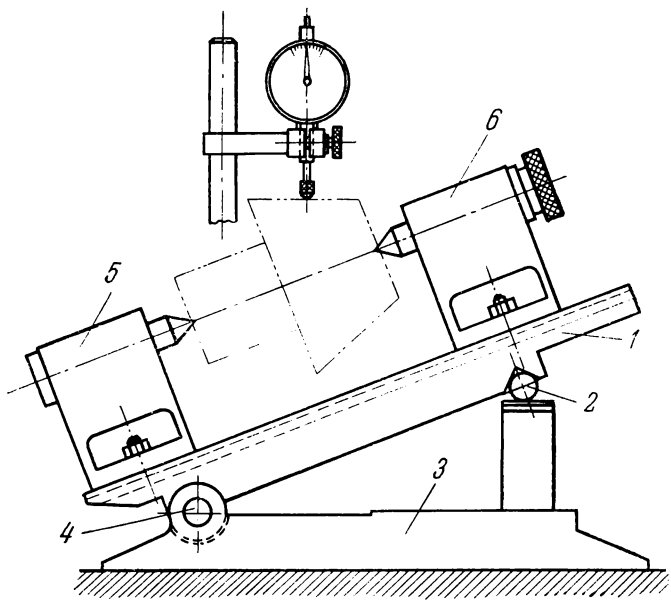


Fig. 133. Device with a sine bar

The set of gauge blocks is placed under the cylindrical plug, and the parallelism between the upper element of the taper and the surface of the plate is tested by means of a dial indicator fixed on a stand. If the angle has been correctly ground, the indicator hand will remain in the zero position.

11-10. GRINDING CYLINDRICAL AND TAPERED HOLES

Selecting the Grinding Wheel. The wheel diameter used for grinding holes should be 0.6 to 0.95 of the hole diameter. The upper limit is used for grinding holes less than 20 mm in diameter, and the lower for grinding larger holes.

Since the spindle of an internal grinder operates at high speeds, it may happen that in grinding large holes the peripheral speed of the wheel is greater than permissible. In such a case, the driving pulley of the spindle drive must be replaced with one of lesser diameter.

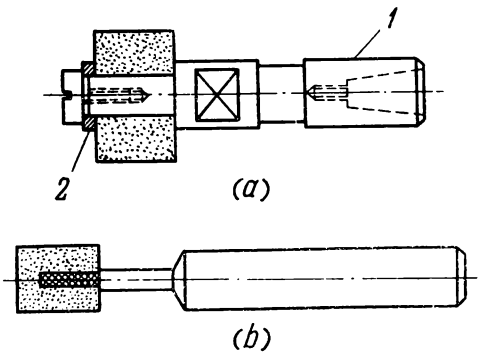


Fig. 134. Mounting a small wheel on a mandrel:
a—clamping with a screw; *b*—rigidly secured

The face width of wheels used for large diameter holes is 50 mm, and this decreases with a decrease in diameter of the hole to be ground. Holes less than 10 or 15 mm in diameter are ground with wheels 8 to 12 mm wide. Wheels more than 50 mm wide are used only in grinding work of a length over 50 mm by the plunge-cut method.

The abrasive material and bond of the wheel are selected from the same considerations as for external grinding. The hardness of the wheel constitutes an exception. Since the arc of contact between the wheel and work is of considerable length, the hardness must be one or two grades lower than that used in the external grinding of the same material.

Mounting and Securing the Wheel. The grinding wheel is mounted and secured on special arbour *1* (Fig. 134*a*), which is then clamped on the wheel spindle. The grinding wheel must contact the shoulder on the mandrel along the entire surface, with a small internal diameter clearance in the hole. Having made sure that these conditions are

met, cardboard spacer *2* is placed in position, and the wheel is firmly clamped by a screw and steel washer. Since the wheel diameter is small, the wheel is not balanced.

A newly mounted wheel always has a considerable runout, and the first truing requires additional time and is associated with the formation of a considerable quantity of dust. Moreover, dressing must be frequently repeated, since the wheel is of small diameter and its service life is extremely limited. For this reason, it is expedient to have a certain number of spare arbours available with mounted and preliminarily trued wheels.

The wheel arbours must be as rigid as possible. Thus, the shortest possible arbour should be selected for each particular job.

For grinding holes less than 10 mm in diameter, wheels are used which are rigidly fixed on special arbours (Fig. 134*b*).

At present, diamond wheels are used for grinding small diameter holes. Although such wheels are very expensive, their application is justified by the considerable increase in output. When mounting such wheels on the spindle, no runout can be permitted, since diamond wheels are not subjected to truing.

Grinding Speeds and Feeds. In specifying grinding speeds and feeds, the less favourable cutting conditions in internal grinding, as compared with external, are taken into consideration. Thus, the infeed used in internal grinding is 0.002 to 0.015 mm per double stroke, which is 2.5 times less than for external grinding. Another means of improving the cutting conditions is to increase the frequency of wheel dressing.

The peripheral wheel speed used for rough grinding is 25 to 30 m per sec, and in finish grinding, 30 to 35 m per sec. To provide such a wheel speed, motorized spindles with a speed up to 48,000 rpm and above are being used to an ever-increasing extent.

Grinding Methods. Through holes are mostly ground by using the *multiple-pass* method, where the rotating wheel has a reciprocating motion along the hole being ground.

The reversing dogs must be set so that the wheel should not emerge from the hole being ground by more than one

half of the wheel width, as otherwise the hole size at the ends will be greater than in the middle.

At the same time, the wheel must not be allowed to emerge from the hole by less than one-third of the wheel width, as otherwise the hole size at the ends will be less than in the middle.

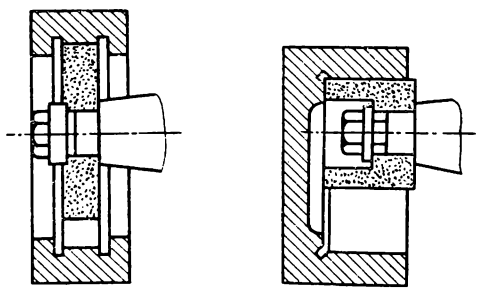


Fig. 135. Internal grinding by the plunge-cut method:
a—grinding a hole; b—grinding a hole and its end face (bottom) simultaneously

In automatic power infeed operation, grinding is continued for some time after the feed is disengaged. The table is usually allowed to run 8 or 10 double strokes without infeed before the grinding wheel is retracted from the hole. If this condition is not observed, the wheel leaves traces on the ground surface as it is withdrawn from the hole.

In internal grinding, the *plunge-cut* method is often applied (Fig. 135). The hole and the internal face (bottom) can be ground simultaneously (Fig. 135*b*). To improve the finish of the ground surface in this case, a slight axial oscillating motion (amplitude 0.2 to 0.4 mm) is imparted to the wheel.

Grinding Tapered Holes. If a through tapered hole is to be ground, grinding is carried out in multiple passes. If, however, the hole ends in a shoulder on one or both sides, which prevents the grinding wheel from being withdrawn longitudinally, the method of plunge-cut grinding is used. In grinding tapered holes by the multiple-pass method,

the work is mounted and held in a chuck or other clamping device, and the workhead, together with the work, is turned through an angle equal to the angle of taper of the cone (Fig. 136).

After a few initial passes and after having obtained the required surface finish for the entire internal surface, the actual angle is measured, and if this deviates beyond the

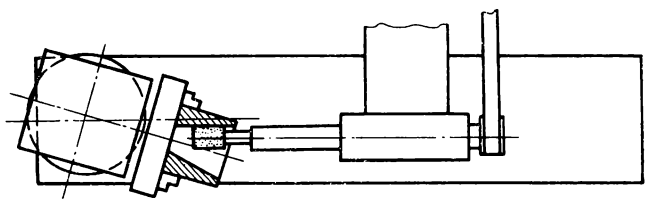


Fig. 136. Internal taper grinding with multiple passes

permissible limits, the angle is corrected in the same way as in external grinding.

In the grinding of tapered holes by plunge-cut grinding, the setting of the wheelhead and the correction of the angle are carried out in the same way as in grinding by multiple passes.

11-11. FORM GRINDING

In mechanical engineering, parts are often encountered that are bodies of revolution but have a shaped contour. Figure 137*a* shows the inner ring of a ball bearing, and Fig. 138*a*, a circular form tool. These parts are bodies of revolution and their contour consists of rectilinear and curvilinear portions. The curvilinear portion of both items is an arc of radius R, and is called the radius section.

Various methods are used for grinding profiled work, depending on the actual conditions. The ring of the ball bearing shown in Fig. 137*a* is a mass-produced item. The grinding of the radius portion (raceway) of the ring is carried out in special semiautomatic grinders.

In Fig. 137*b* a grinding method involving rocking of the work is shown. Spindle *1* of the grinding wheel is slowly fed in the direction of arrow *A*. The work spindle with bear-

ring ring 2 mounted on it rotates and has a rocking motion about a vertical axis passing through the centre of the arc O of the raceway.

The profile of the ground raceway is checked with a limit gauge (Fig. 137*c*). The distance from the centre of radius R to the locating surface is greater on the Go

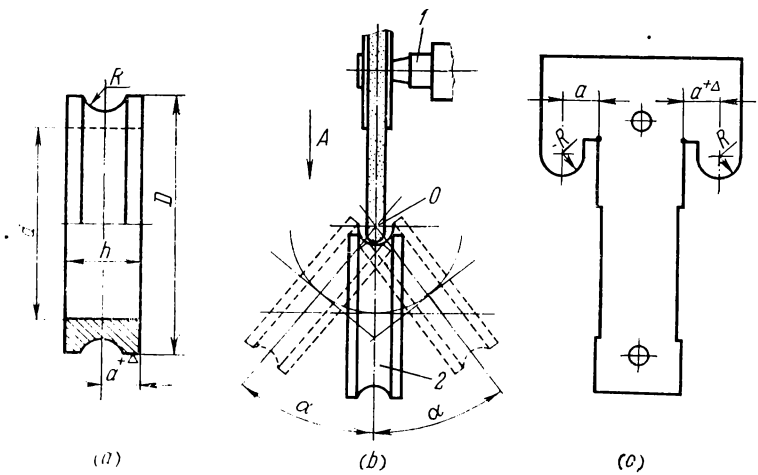


Fig. 137. Form grinding:
a — internal ring of a ball bearing with the raceway; *b*—grinding the raceway by rocking the work; *c* — gauge for checking the raceway profile

side of the gauge than on the Not-go side by the value of the tolerance Δ for this size. The radius of the raceway is checked by two balls of the corresponding limiting sizes.

The circular form tool shown in Fig. 138*a* is manufactured on a small-lot scale, and is machined in general-purpose machine tools. For grinding the profile, a wheel of a width 2 to 3 mm greater than that of the tool to be ground is used.

After mounting the wheel on the wheel spindle, it is trued with a profile that is the reverse of that required on the tool. Then the mandrel, on which the tool is mounted, is set up between the centres, advanced to the formed grinding wheel, and the wheel and work spindles are started. Grinding is carried out by infeed, as in the grinding of any other workpiece by the plunge-cut method.

The grinding wheel is crush-form dressed with a steel roller of the corresponding profile.

The tool profile is checked with a gauge, and the profile of the dressed wheel, with a check gauge (Fig. 138*b*).

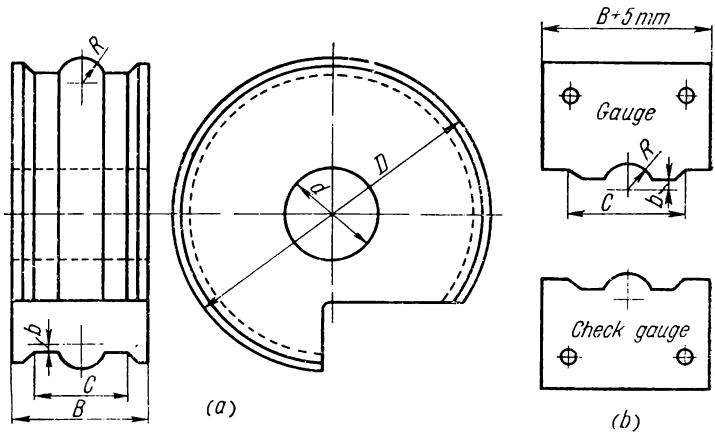


Fig. 138. Circular form tool (*a*) with gauges (*b*)

11-12. HIGH-VELOCITY GRINDING

One of the methods for greatly increasing the output in grinding is the use of high-velocity grinding. In high-velocity grinding the peripheral speed of the grinding wheel is increased to 50 m per sec, instead of the usually employed 25 to 30 m per sec. Simultaneously, the peripheral speed of the work is increased to 60 m per min or higher.

When the grinding wheel speed is increased, the average thickness of the metal chip removed by an individual abrasive grain decreases, and hence the load on this grain is reduced. As the load is reduced, breaking out of the abrasive grains from the wheel bond is retarded.

Experience in the application of high speeds in grinding has shown that such an increase in the hardness of the wheel leads to an increase in its stability and in the specific removal of metal, i.e., in the ratio of the weight of the metal removed to the weight of the consumed portion of the abrasive wheel. Thus, for example, in the grinding of the

raceway of the outer ring of a ball bearing at a speed of 35 m per sec, the wheel will grind 40 rings between dressings, and at a wheel speed of 50 m per sec, the life of the same wheel will increase to 60 rings.

This means that by changing to high-velocity grinding an economy is achieved not only by a considerable reduction of the machine time per operation, but also by reducing the consumption of the wheel, the handling time required for changing a worn wheel for a new one, and the time to reset the grinder.

The increase in the peripheral speed of the grinding wheel also has a beneficial effect on the finish of the ground surface.

A peripheral grinding speed of 50 m per sec is permissible only when special high-velocity wheels are used.

High-velocity wheels are made from white aluminium oxide (9I5) or monocorundum (M) using a special high-strength vitrified bond. Wheels with resinoid and rubber bonds are also used.

The structure of high-velocity wheels must not be lower than 9. High-porosity wheels, i.e., wheels in which the pore size is greater than that of wheels of structure 12, are being used more and more in high-velocity grinding. These wheels have a lower specific gravity, and for this reason the centrifugal forces, developed during the operation of high-porosity wheels, are considerably less than in ordinary wheels. This has a beneficial effect on the working conditions of the spindle bearings and reduces the danger of wheel rupture during operation. A great advantage of high-porosity wheels is their lesser tendency to become loaded, and also the possibility of the cooling liquid being fed through the pores of the wheel.

Preparation of the Machine. Prior to changing the machine over to high-velocity grinding, its condition must be thoroughly checked. Starting with the grinding wheel diameter, the required rotational speed of the spindle is determined to obtain a grinding speed of 50 m per sec, and in accordance with this, the diameters of the motor and spindle pulleys are determined. The pulleys must have no runout. A pulley is best mounted on a taper without the use of a key, but in cases where the latter cannot be

avoided, care must be taken that the mounting of the pulley does not lead to unbalance of the spindle.

In high-velocity grinding, the peripheral speed of the work is increased up to 40% over that normally used. As the speed of the work increases, so does the cutting force P_z.

An increase of this force, in combination with the increased peripheral speed of the grinding wheel, leads to some increase in power consumption. Because of this, on changing the machine over to high-velocity grinding, the power consumption at maximum load must be calculated, and the electric motor of the wheelhead replaced with a more powerful one. Thus, on changing over machines to the high-velocity grinding of raceways of outer ball bearing rings, the power of the wheel spindle motor was increased by 75%.

By adjusting the bearings of the wheel spindle, the clearance is increased by 0.005 to 0.01 mm. The lubricant supply to the spindle bearing is also increased. The rapidly revolving components are checked for unbalance and the necessary balancing is performed.

Rigidity of the machine is very important for normal operation in high-velocity grinding. To increase the rigidity, the ways of all slides must be accurately scraped and the taper gibs adjusted to a smaller clearance.

The quantity of heat generated in high-velocity grinding is considerably greater, and therefore the volume of coolant flow to the grinding zone must be increased. For this purpose, the coolant pump is usually exchanged for a more powerful one.

The steady temperature of the coolant and the work must be between 20 and 25° C. Owing to the increase of the total quantity of heat which must be removed by the coolant, the quantity of circulating fluid and hence the tank capacity of the cooling system must be increased by 25 to 40%.

High-velocity grinding considerably reduces machining time. In modernizing machines, provision must also be made for a maximum reduction of handling time. To this end, the grinders are provided with instruments for measuring the work during grinding.

Operator's Safety in High-velocity Grinding. Prior to introducing high-velocity grinding, stringent measures must be taken to ensure operator's safety. First of all,

the wheels must be tested for a peripheral speed of 75 m per sec immediately prior to their dispatch from the abrasive stores to the workplace.

Handling of the wheels must be organized so as to completely exclude any possibility of damage to them.

High-velocity wheels must be subjected to careful balancing. The latter is carried out in two stages: (1) when the wheel is mounted on the sleeve and (2) after the first dressing.

As the wheel diameter decreases during grinding, its balance may be impaired, resulting in vibrations. In such a case, operation must be interrupted and the wheel rebalanced.

Apart from observing all the measures enumerated above, one must be prepared for the possibility of the wheel bursting during operation. Should a wheel rotating at a high speed burst, the standard wheel guard may prove to be insufficiently strong. Therefore, a cast iron guard is replaced by a steel one, and those machines which, prior to the change-over to high-velocity grinding, were provided with steel guards must have them changed to stronger ones.

The angle of opening of the guard must be as small as possible. As the wheel wears down, the guard must be moved so that the opening is in the immediate proximity of the wheel.

When a wheelhead spindle, on which a new wheel has been mounted, is switched on, the operator should not stand in front of the rotating wheel.

11-13. AUTOMATION OF GRINDING OPERATIONS

One of the basic methods of automating production processes is the introduction of automatic machines and automated production lines.

The automation of grinding operations presents considerable difficulties owing to the rigid requirements with respect to dimensional accuracy and surface finish of the ground workpieces. The mechanisms used in metal-cutting machine tools for feeding the cutting tool or the work do not guarantee the required accuracy of their relative positions, and hence the attainment of the accurate dimensions which are

normally achieved by grinding. The rapid wear of the grinding wheel also complicates the automation of the process.

The automation of grinding operations is brought about by the use of mechanical, hydraulic, pneumatic and electrical facilities.

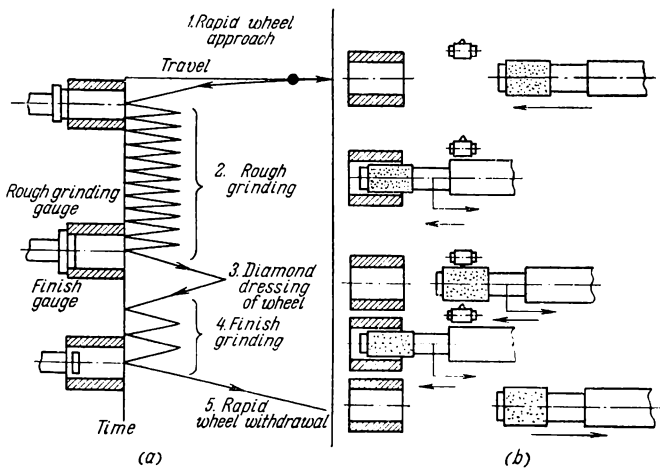


Fig. 139. Diagram of an automatic bore grinding cycle:
a—position of gauges; *b*—position of a grinding wheel

Let us consider an example of automation in grinding the bore of the inner ring of a ball bearing, the basis of which is the automatic measurement of the bore by a two-step plug gauge. In this case, the size of the first step is equal to that of the bore after rough grinding, and the size of the second step is equal to the final size of the bore. This gauge is located at the rear end of the bore to be ground and on the same axis. The gauge is linked to the grinding wheel in such a way that it approaches the rear end of the workpiece, attempting to enter its bore, by spring action, when the wheel travels to the right and comes out of the ground bore.

When the direction of the wheel travel changes to the left, the gauge also travels to the left, making way for the grinding wheel to overtravel the bore at its rear end.

Figure 139 shows a diagram of an automatic operating cycle for grinding a bore, consisting of the following operations:

1. The rotating grinding wheel rapidly approaches the rotating work automatically and enters the bore. The crosswise position of the wheelhead corresponds to the maximum grinding allowance of the bore.

2. Grinding wheel reciprocation is automatically switched on. Infeed is effected at each double stroke at the rate assigned for rough grinding. When the grinding wheel is in the extreme right position, the rough grinding gauge approaches the bore from the left and attempts to enter it.

3. The bore has reached the size assigned for rough grinding, and the rough grinding gauge enters. Then the grinding wheel is automatically withdrawn for dressing.

4. When dressing is completed, the grinding wheel automatically enters the rough ground bore, and finish grinding commences at a reduced rate of infeed.

5. The bore has reached the final size and the finish gauge enters. The grinding wheel is withdrawn to its initial position and the work spindle stops rotating.

When the ground workpiece is removed and the next one set up, the automatic cycle is repeated.

In this case, the work is gripped in a diaphragm chuck; the control of the automatic grinding cycle (commands for approach and withdrawal of the grinding wheel, change-over from rough to finish feed, etc.) is effected by an electrical device, while the table carrying the wheelhead is hydraulically traversed.

On the basis of automatic machine tools, automatic transfer machines and automated production lines are developed which perform various grinding operations consecutively. The machine tools of the automatic transfer machines and production lines are linked by conveyors or other handling facilities of various types.

11-14. REJECTIONS AND MEASURES TAKEN TO PREVENT THEM

To prevent rejections in grinding is particularly important, since a grinding operator who produces rejects ruins

not only his own work, but also that done during the preceding operations.

The main types of rejects in grinding are:

(1) deviation from the nominal size beyond the tolerance limits;

(2) out-of-roundness;

(3) lack of straightness;

(4) taper;

(5) chatter marks on the surface;

(6) burns;

(7) grinding cracks.

Deviation of dimensions from the specified values can be due only either to the carelessness of the operator or his incompetence.

Out-of-roundness can be due to the following:

(a) unsatisfactory condition of the centre holes; this can be prevented by keeping a constant check on the centre holes of the work, and, if necessary, lapping and cleaning them up;

(b) insufficiently tight fit of the headstock and footstock centres;

(c) poor condition of the spindle bearings of the headstock (in the case of grinding in a chuck).

Lack of straightness of the work being ground is the result of excessive wheel wear. When this defect occurs, the wheel must be dressed.

Taper in grinding cylindrical work and deviations from the preset taper angle in grinding tapered work occur when the swivel table or the headstock is not firmly fixed in position.

Chatter marks on the surface of the work are caused by vibrations of the machine, the main reasons for which are:

(a) lack of balance of the wheel; the wheel is either poorly balanced or it has shifted during operation, owing to insufficiently firm clamping;

(b) poor condition of the wheelhead spindle bearings;

(c) poor condition of the transmission belts or mechanical damage to transmission components.

When the machine is adjusted, first of all vibrations must be eliminated. Vibrations can be very easily detected

by lightly touching the headstock or the wheelhead with the hand.

Burns on the workpiece are due to excessive heat generation during grinding at the point of contact between the wheel and the workpiece as a result of:

(a) too high a hardness of the wheel;
(b) too high a peripheral speed of the wheel;
(c) insufficient peripheral speed of the rotating work;
(d) too high a rate of infeed;
(e) insufficient cooling.

Burns are a very dangerous type of defect, since they cannot always be discovered in initial inspection.

Grinding cracks are formed particularly often in the grinding of cemented carbide parts. They are sometimes difficult to detect with the naked eye. The reason for the formation of grinding cracks is the poor thermal conductivity of the cemented carbide. Therefore it must be ground at very low peripheral grinding wheel speeds (12 to 14 m per sec). A wheel of M1 or M2 hardness and high porosity is used.

11-15. SAFETY TECHNIQUES

Rupture of the wheel is possible during the operation of grinding machines. Therefore, wheel guards are installed on grinding machines to protect the operator and other personnel. Cast iron guards are commonly used on cylindrical grinders operating at a peripheral wheel speed up to 30 or 35 m per sec, while machines designed for high-velocity grinding are provided with guards of welded steel plate 8 to 20 mm in thickness.

Internal grinding with an unprotected wheel is also dangerous, and therefore the grinding wheel must be enclosed in a guard. Since in internal grinding the wheel enters the bore to be ground, the wheel guard must be retractable. Fig. 140 shows one design of a wheel guard for internal grinding. Sleeve *1* is screwed to the front face of the wheelhead housing. Inside the sleeve is multicoil spring *2* allowing a compression equal to the stroke of the grinding wheel and developing a relatively small force. Inside the sleeve moves sliding block *3* which is secured to outer sleeve *5*

by means of pin *4*. Inside the sleeve is an appropriate groove for the movement of pin *4*. Wheel guard *6* is welded to outer sleeve *5*. The wheel guard has a section cut out to allow the wheel to be dressed. In the idle position, spring *2* holds sleeve *5*, and with it the guard in the extreme forward position where the wheel is enclosed by the guard.

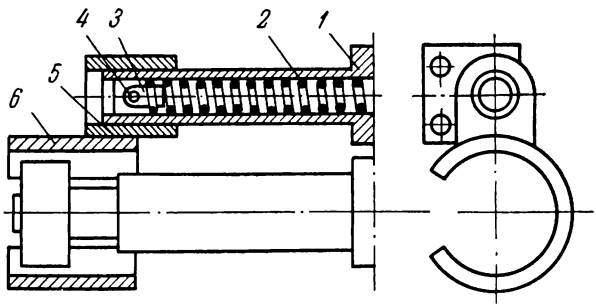


Fig. 140. Wheel guard for internal grinding

During operation, when the wheel spindle approaches the work, the end face of the guard runs up against the work, compressing the spring. This lets the wheel pass into the hole to be ground. When the wheel comes out of the ground hole, the spring returns the guard to its initial position.

When the grinding wheel is mounted on a sleeve between flanges, cardboard gaskets (blotters) 0.8 to 1 mm thick must be inserted between the sides of the wheel and the flanges.

Grinding wheels having a hole, the axis of which is not perpendicular to the sides of the wheel, must not be used in operation, since the bearing between the sides of the wheel and the flanges will be incomplete. When the wheel is clamped, dangerous stresses may arise, as a result of which the wheel may be cracked.

The following basic safety rules must be observed in operating grinding machines:

1. Each grinding machine must be handled only by those operators who are in charge of it. All others must not be allowed to operate the machine.

2. Prior to starting operation, the direction of rotation of the wheel spindle must be checked. Rotation in the wrong

direction can lead to a loosening of the screw clamping the wheel sleeve on the spindle, as a result of which the rotating grinding wheel may fly off the spindle.

3. The setting and clamping of attachments and of the workpiece must be checked. A poorly clamped workpiece may be thrown off during grinding.

4. When workpieces weighing over 15 or 20 kg are set up in the machine, special handling devices and hoisting gear should be used.

5. The work must not be measured whilst the machine is in motion. To measure the work, it must be withdrawn from the grinding wheel and the headstock spindle must be stopped.

6. During operation, and particularly during wheel dressing, the operator must wear goggles to protect his eyes against flying particles of the wheel.

7. All belt and gear transmissions of the machine, as well as projecting ends of rotating shafts, must be enclosed by guards.

8. The machine must be disconnected from the power supply with the main line switch prior to cleaning and lubricating.

9. To avoid electric shocks, the operator must observe all electric safety rules.

INDEX

A

Abrasive materials 125, 245
Abrasive resistance of metals 14
Abrasive wheel dresser 251
Abrasives, applications of 129
Abrasives, coated 141
Accuracy, machining 66
Accuracy of measurement 82
Accuracy tests 238
Actual size 68
Addition of forces 113
Air gauge 106
Allowance 242
Alloy, commercially pure 11
Alloyed tool steel 24
Alloying elements 22
Alloys, antifriction 33
Alloys, magnesium 32
Alternating current 192
Aluminium 30
Aluminium oxide abrasive 127
Aluminizing 27
Amount of taper 275
Angle measurement 93
Angle of taper 275
Annealing 25
Antifriction alloys 33
Arc of contact 148
Arm of force 115
Assembly drawing 60
Asynchronous motor 194
Automatic caliper-type gauging device 109
Automatic gauging 108
Automatic operating cycle 291
Automation of grinding operations 289
Auxiliary location surface 243
Average chip thickness 148
Axle 167

B

Babbitt 33
Backing 141
Balancing a grinding wheel 248
Base of cylindrical grinder 204
Basic-hole system 73
Basic-shaft system 73
Bearing, antifriction 166
Bearing, spindle 163
Belt, abrasive 141
Belts 169
Bench work 43
Bessemer steel 20
Bond 245
Bonding materials 133
Boron carbide abrasive 127
Borosilicon carbide abrasive 127
Brass 31
Breakable pin 169
Brinell hardness tester 16
Bronze 30
Burns, grinding 156

C

Calorizing 27
Cam grinding attachment 260
Carbon steels, structural 21
Carbon tool steels 23
Carburizing 26-27

Case-hardening 26
Cast cutting alloys 28
Cast iron 19
Casting techniques 37-38
Cemented carbides 28
Centre of gravity 114
Centre hole 264
Centre mandrel 255
Centreless grinder 232
Centreless grinding 232-233
Centres 253
Centrifugal casting 38
Centrifugal force 115
Centripetal force 116
Ceramic-tool materials 29
Chain transmission 173
Checking tapers 277
Chemical corrosion 34
Chip formation 122, 146
Chip thickness, average 148
Chip thickness, mean 149
Chucks, clamping 257-259
Classification, machine tool 160
Clearance 69
Cloth, abrasive 141
Clutches 167
Coated abrasives 141
Coefficient of friction 116
Combined traverse and plunge-cut grinding 270
Commercially pure alloys 11
Commercially pure metals 11
Conductance 191
Conductivity, electrical 12
Conductivity, thermal 13
Contact, arc of 148
Contactor control 198
Continuous chip 122
Cooling fluid 157
Cooling system 225
Copper 30
Corrosion 33
Corundum 126
Couplings 167
Cracks, grinding 157
Crush dressing 251
Crystal lattice 18
Cutting alloys 27
Cutting fluids 37
Cutting force 150
Cyaniding 27
Cycle, automatic operating 291
Cylinder, working 183
Cylindrical grinder 201
Cylindrical grinder units 204-218

D

Deformation 118
Delta connection 193
Density 12
Depth of cut 145
Determining wheel hardness 136
Diagram, gearing 61, 162
Diagram, kinetic 61, 162
Dial comparator 97
Dial indicator 99
Dial scale, grinding to 220
Dial-type adjustable snap gauge 100
Diamond 126
Diamond dressing 253
Diaphragm chuck 259
Die casting 38
Dimensioning 50
Dimension, free 67
Dimension, mating 66
Direct current 191
Directional valve 186
Discontinuous chip 122
Dog, driving 253
Drawing 40
Drawing, assembly 60
Drawing lines 48
Drawing scales 47
Drawing, working 44
Dresser, abrasive wheel 251
Dresser, star-type 250
Dressing, wheel 249
Dressing, crush 251
Dressing, diamond 253
Driving dog 253
Duralumin 32

E

Efficiency 118
Elastic limit 15
Elasticity of metals 14
Electric contact transmitter 107
Electrical conductivity 12
Electrical resistivity 12

Electrical safety measures 199
Electrochemical corrosion 34
Electromotive force 191
Emery 126
Expansion mandrel 256
Extrusion 40

F

Fabricating methods 37
Fabricating properties 18
Face grinding 270
Feed motion 162
Feed rod 167
Feed, rotary 145
Finish, surface 78
Fits 70
Fixed fit 70
Fluidity 18
Footstock of cylindrical grinder 212
Force 113
Forgeability 18
Forging 40
Form grinding 284
Foundry practice 37
Four-jaw chuck 257
Free dimension 67
Frequency 192
Friction clutch 169
Friction drive 175
Frictional force 116
Frontal elevation 46
Full-depth grinding 267
Fuse 199

G

Garnet 126
Gas carburizing 27
Gauge block 105
Gear transmission 173
Gearing 173
Gearing diagram 61, 162
Grade of wheel 135
Grain size 128, 245
Grey iron 20
Grinder, centreless 232
Grinder, cylindrical 201
Grinder, internal 229
Grinding automation 289
Grinding burns 157
Grinding, combined traverse and plunge-cut 270
Grinding conditions 143
Grinding cracks 157
Grinding to dial scale 220
Grinding, face 270
Grinding feeds 282
Grinding, form 284
Grinding, full-depth 267
Grinding, high-velocity 286
Grinding holes 280
Grinding methods 265, 276, 282
Grinding, multiple-pass 282
Grinding, plunge-cut 269, 283
Grinding to positive stop 220
Grinding process 142
Grinding, single-pass 267
Grinding speeds 282
Grinding tapered holes 283
Grinding tapers 274
Grinding, traverse 266
Grinding wheel selection 245, 280
Grinding wheel testing 140

H

Hardening 25
Hardness of metals 14
Hardness tester, Brinell 16
Hardness tester, Rockwell 17
Hardness, grinding wheel 135
Headstock of cylindrical grinder 209
Headstock of internal grinder 230
Heat factor 147
Heat generation 156
Heat treatment 24
Heating of work 155
High-velocity grinding 286
Hole grinding 280
Hydraulic drive 177
Hydraulic loss 178

I

Idler pulley 172
Induction pickup 107
Infeed centreless grinding 233
Infeed, rate of 145
Infeed, wheelhead 218

Inhibitor, volatile 35
Inside dial gauge 103
Inside micrometer 91
Instantaneous temperature 156
Interchangeability 65
Intercrystalline corrosion 34
Interference 69
Internal grinder 229
Internal grinder units 230-232
Internal grinding 224
Intergranular corrosion 34

K

Kinematic diagrams 61, 162
Knife switch 196

L

Lattice, crystal 18
Layout, tooling 244
Lead 30
Life, wheel 155
Limit, elastic 15
Limit gauge 104
Limit of proportionality 15
Limits of size 68
Liquid carburizing 27
Location datum surface 243
Longitudinal table traverse 221
Longitudinal traverse 232
Lubricants 36
Lubrication system 225

M

Machinability 18
Machine steel 22
Machine tool classification 160
Machining 41
Machining accuracy 66
Magnesium 30
Magnesium alloys 32
Magnesium oxychloride bond 134
Magnetic properties 13
Magnetic starter 198
Mandrel, centre 255
Mandrel, expansion 256
Manufacturing process 242
Marking of wheels 139
Master process sheet 244
Mating dimensions 66
Mating parts 66
Mean chip thickness 149
Measuring accuracy 82
Measuring error 83
Mechanical loss 178
Mechanical working of metals 39
Mechanism 117
Melting point 13
Mesh size 128
Metals, commercially pure 11
Metals, properties of 12
Metals, structure of 18
Metering-in control 186
Metering-out control 186
Methods, grinding 265, 276, 282
Microirregularities 79
Micrometer caliper 88
Micrometer depth gauge 91
Micron powders 131
Milling 123
Moment of force 114
Motion, feed 162
Motion, path of 111
Motion, primary cutting 161
Motor reversal 195
Motor, squirrel-cage induction 194
Mounting the grinding wheel 248, 281
Movable fit 70
Multiple-pass grinding 282

N

Nitriding 27
Nominal size 67
Normalizing 25

O

Ohm's law 191
Operation 242
Operation element 242
Operation sheet 244
Operational allowance 242
Operator's safety 288
Orthographic projection 45
Overall efficiency 179
Overrunning clutch 169

P

Pack carburizing 26
Paper, abrasive 141
Parallel connection 191
Pass 242
Path of motion 111
Performance test 240
Period 192
Permanent-mould casting 38
Photoelectric transducer 108
Pig iron 19
Plasticity of metals 14, 18
Plastics 36
Plug gauge 104
Plunge-cut grinding 268, 283
Positive stop, grinding to 220
Powders, micron 131
Power factor 193
Power rating 117
Power required in grinding 152
Power screw 174
Power table infeed 221
Power wheel approach 223
Primary cutting motion 161
Primary location surface 243
Process manufacturing 242
Process, sheet 244
Properties, fabricating 18
Properties of metals 12
Proportionality limit 15
Protractor 94
Pump, hydraulic 180
Push-button station 197

Q

Quartz 126

R

Radial force 151
Radial-piston pump 183
Rate of infeed 145
Rate of traverse 145
Ratio, transmission 172, 173, 174, 176
Regulating wheel 232
Rejects, types of 292
Relief valve 186
Required power in grinding 152
Resinoid bond 134
Resistance, specific 190
Resistivity, electrical 12
Resultant force 114
Reversal, motor 195
Rockwell hardness tester 17
Roller chain 173
Rolling 39
Rolling friction 116
Rotary feed 145
Rotary motion 112
Rotary packet-type switch 196
Routing sheet 244
Rubber bond 134

S

Safety clutch 169
Safety coupling 169
Safety measures, electrical 199
Safety, operator's 288
Safety rules 294
Safety techniques 293
Screw pitch comparator 97
Screw pitch gauge 96
Screw, power 174
Screw threads 56
Section, broken 56
Section, offset 56
Section, removed 52
Section, revolved 52
Sectional view 53
Segmental chip 122
Self-centring three-jaw chuck 257
Self-sharpening 154
Semiautomatic cycle 226
Series connection 191
Setting-up operations 264
Shaft 166
Shapes, wheel 138
Sheet, abrasive 141
Sheet, process 244
Silent chain 173
Silicate bond 134
Silicon carbide abrasive 127
Silumin 32
Sine bar 279
Single-pass grinding 267
Single-point tools 120
Size, actual 68
Size, limits of 68

Size, nominal 67
Sketch 44
Slide unit, universal 216
Sliding friction 116
Snap gauge 104
Sparking out 146
Specific resistance 190
Speed, wheel 143
Speed, work 144
Spindle 162
Spindle bearing 163
Spindle nose 163
Spindle, wheel 214
Spur-gear pump 180
Squirrel-cage induction motor 194
Star connection 193
Starter, three-pole push-button 196
Steady rest 256
Steady temperature 156
Steel, acid 21
Steel, alloyed tool 24
Steel, basic 21
Steel, Bessemer 20
Steel, carbon tool 23
Steel, machine 22
Steel, structural carbon 21
Steel, Thomas 20
Stepless friction drive 177
Strain 118
Strength of metals 13
Structural carbon steel 21
Structure of grinding wheel 136
Structure of metals 18
Subzero treatment 26
Suggestion, time-and-labour-saving 243
Surface finish 78
Surface, location 243
Switch, knife 196
Synthetic diamond 126

T

Table of cylindrical grinder 205
Table traverse mechanism 206
Tangential force 150
Taper, amount of 275
Taper grinding 274
Tapered holes, grinding 283
Tapers, checking 277
Temperature, instantaneous 156
Temperature, steady 156
Tempering 25
Tensile tests 14
Testing grinding wheels 140
Tests, accuracy 238
Tests, performance 240
Thermal conductivity 13
Thermal relay 199
Thermoplastic materials 36
Thermosetting plastics 36
Thomas steel 20
Thread inspection 96
Threads, screw 56
Three-jaw pneumatic chuck 259
Three-pole push-button starter 196
Throttle valve 185
Through-feed centreless grinding 233
Time-and-labour-saving suggestion 243
Tin 30
Tolerance 68
Tool, single-point 41
Tool steel, alloyed 24
Tool steel, carbon 23
Tooling layout 244
Transformer 194
Transition fit 70
Transmission ratio 172, 173, 174, 176
Traverse grinding 266
Traverse, rate of 145
Truing 249

V

V-belt 172
Vane pump 182
Vector 113
Vernier caliper 84
Views in drawings 46
Vitrified bond 133
Volatile inhibitor 35
Voltage 191
Volumetric loss 178
Vulcanized rubber 35

W

Weldability 18
Welding 43
Wheel balancing 248
Wheel grade 135, 245
Wheel hardness 135, 245
Wheel hardness determination 136
Wheel infeed 231
Wheel life 155
Wheel marking 139
Wheel mounting 248, 281
Wheel, regulating 232
Wheel shapes 138
Wheel speed 143
Wheel spindle 214
Wheel structure 136, 245
Wheelhead of cylindrical grinder 214
Wheelhead infeed mechanism 218
Wheelhead of internal grinder 231
White iron 19
Wood 35
Work, heating of 155
Work speed 144
Work-hardening 123
Working fluid 178
Worm gearing 174

Y

Yield point 15

Z

Zinc 30

TO THE READER

Mir Publishers would be grateful for your comments on the content, translation and design of this book. We would also be pleased to receive any other suggestions you may wish to make.

Our address is: Mir Publishers, 2, Pervy Rizhsky Peveulok, Moscow, USSR.

Printed in the Union of Soviet Socialist Republics